A MULTISCALE FRAMEWORK FOR MIXED REALITY WALKING TOURS

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A MULTISCALE FRAMEWORK FOR MIXED REALITY WALKING TOURS

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LIST OF SYMBOLS AND ABBREVIATIONS

MR	Mixed Reality
AR	Augmented Reality
MRSF	Mixed Reality Scale Framework
HCC	Human-Centered Computing
MRSF	Mixed Reality Scale Framework

SUMMARY

Mixed Reality experiences, that blend physical and virtual objects, have become commonplace on handheld computing devices. One common application of these technologies is their use in cultural heritage "walking tours." These tours provide information about the surrounding environment in a variety of contexts, to suit the needs and interests of different groups of participants. Using the familiar "campus tour" as a canonical example, this dissertation investigates the technical and cognitive processes involved in transferring this tour from its physical and analog form into Mixed Reality. Using the concept of *spatial scale* borrowed from cognitive geography, this work identifies the need to create and maintain *continuity* across different scales of spatial experience as being of paramount importance to successful Mixed Reality walking tours. The concepts of *scale transitions, coordination of representations across scales,* and *scale-matching* are shown to be essential to maintaining the continuity of experience. Specific techniques that embody these concepts are also discussed and demonstrated in a number of Mixed Reality examples, including in the context of a successful deployment of a Mixed Reality Tour of the Georgia Tech campus. The potential for a "Language of Mixed Reality" based on the concepts outlined in this work is also discussed, and a general framework, called the *Mixed Reality Scale Framework* is shown to meet all the necessary criteria for being a cognitive theory of Human-Centered Computing in the context of Mixed Reality.

CHAPTER 1

INTRODUCTION:

SPATIAL SCALE IN MIXED REALITY

1.1 Background and Motivation

The first decade of the 21st Century has seen an explosion in the number and kind of mobile computing experiences. Recent developments in the size and power of mobile devices, combined with broadband wireless information infrastructure, have made mobile and ubiquitous computing an everyday activity for mainstream technology users. In this new computing paradigm, the always-available handheld and networked device, typically a “smartphone” or “tablet,” is commonly used to access information in a variety of locations. However, a certain class of applications, which I refer to as Mixed Reality (MR), goes beyond simply providing access to information from various locations. MR applications provide information that is dependent on a physical place or object. These applications can therefore be said to mediate the human experience of physical space by adding virtual contexts, objects, or actions, and effectively creating a hybrid physical-virtual reality.

One class of MR applications, what I refer to as MR Walking Tours, have begun to appear on the mobile web, or as downloadable “Apps” for smartphones and tablets. These experiences are the digital descendants of the common analog walking tour, in which an individual or group traverses an environment using audio or paper materials to provide context and information about points of interest. MR walking tours attempt to update this conventional form by taking advantage of personal handheld digital technologies to provide additional contexts and interactions that are not possible in purely analog tours. MR walking tours come in many forms, some simply use the storage and display capabilities of devices to store and access information that would typically be given in paper or audio form. Other experiences take advantage of an always-on Internet connection to tailor information based on current location or topics of interest. The most advanced MR walking tours create new modes of interaction, and display multimedia content that is visually mixed into the surrounding environment when the combination of the device camera and display are used as a “window” onto the physical world. While the potential value of these tour experiences seems clear, creating them is much more complex and murky.

The campus tour experience I treat as an exemplar of MR walking tours requires the delivery and integration of information at multiple *spatial scales,* a fact that contrasts with existing MR design methodologies and analytical frameworks. To properly inform the design of these experiences, we must define new concepts and strategies that address the unique challenges inherent to *multiscale* MR experience. These include understanding how spatial scale manifests itself in the design process of MR experiences, identifying the role and effects of spatial scale the user experience to identify potential opportunities for design intervention, and developing strategies that leverage these findings to produce an MR tour experience that operates on multiple spatial scales. Through an analysis of technological, cognitive, and design elements, I develop a framework for conceptualizing MR walking tours that can be used in both the design and analysis of these experiences. The following thesis statement summarizes the value of such a framework:

> *A multiscale framework for Mixed Reality walking tours can identify new constructs for design and analysis, inform design decisions, explain empirical results, and guide the development of a MR walking tour and the tools for its creation and maintenance.*

1.2 Research Approach

In support of the above thesis statement I provide evidence gathered through artifact and discourse analysis of existing MR experiences and published research, semi-structured interviews with designers of MR systems, close-reading of canonical texts, participant observation of analog and MR campus tour experiences, and reflection on the design of a MR campus tour and its associated tools. The following hypotheses and research questions are intended to guide the investigation into the role of scale in MR experiences and determine central concepts and strategies for use in the multiscale design of MR walking tours.

1.2.1 Research Questions

> *Question 1:* What role does spatial scale play in the design, analysis, and use of MR experiences?
>
> *Question 2*: Does articulating the influence of spatial scale offer insight that could aid an iterative design process? What scale-based strategies do MR designers use? How do these strategies affect the user experiences or behaviors?
>
> *Question 3*: What is the role of scale in the analog campus tour? In what ways could a MR version of this tour use scale more productively? How does spatial scale inform or constrain the construction of the MR tour and affect the experience of participants?
>
> *Question 4*: Does a framework built on the concept of spatial scale (the MRSF) meet Halverson's criteria for a cognitive theory of HCI?

1.2.2 Hypotheses

> *Hypothesis 1*: Existing MR experiences can be analyzed in terms of their use of spatial scale to account for observed behaviors and to isolate new constructs for future consideration in design and analysis that are not accounted for by current approaches.
>
> *Hypothesis 2*: Designers of MR experiences intuitively make use of spatial scale. When we examine the thinking involved in the MR design process, we can identify the role of spatial scale and extract concepts and strategies that inform the design process.
>
> *Hypothesis3*: Applying a multiscale framework to the analog campus walking tour will result in new knowledge that can be transferred to a MR campus tour by locating opportunities for design intervention and providing explanations of user behaviors.
>
> *Hypothesis4*: A multiscale framework for MR walking tours has rhetorical, descriptive, inferential, and application power as described by Halverson (Halverson, 2002).

1.3 Contributions

The main contributions of this dissertation and the evidence supporting them are summarized below, these include: (1) a rich description of the role of spatial scale in MR experiences and the resultant Mixed Reality Scale Framework (MRSF); (2) an articulation of the importance of preserving *continuity* across scales to facilitate the meaning-making process in multiscale MR experiences, and the identification of the strategies for achieving continuity, including: *coordination of representations between scales*, *scale transitions,* and *scale matching* as major concepts in multiscale design; (3) some interactive techniques that facilitate continuity that can be used in developing MR experiences, including: *environmental approximation*, *panoramic sliding*, and *embodied triggers*; and (4) the GTour walking tour and supporting web toolkit available to Georgia Tech students.

1.3.1 The Mixed Reality Scale Framework

The Mixed Reality Scale Framework (MRSF), is an amalgam of work in spatial cognition done by Montello (Montello, 1993), and further refined in the work of Freundshuh & Egenhofer (Freundschuh and Egenhofer, 1997). It divides space into five distinct scales as described below:

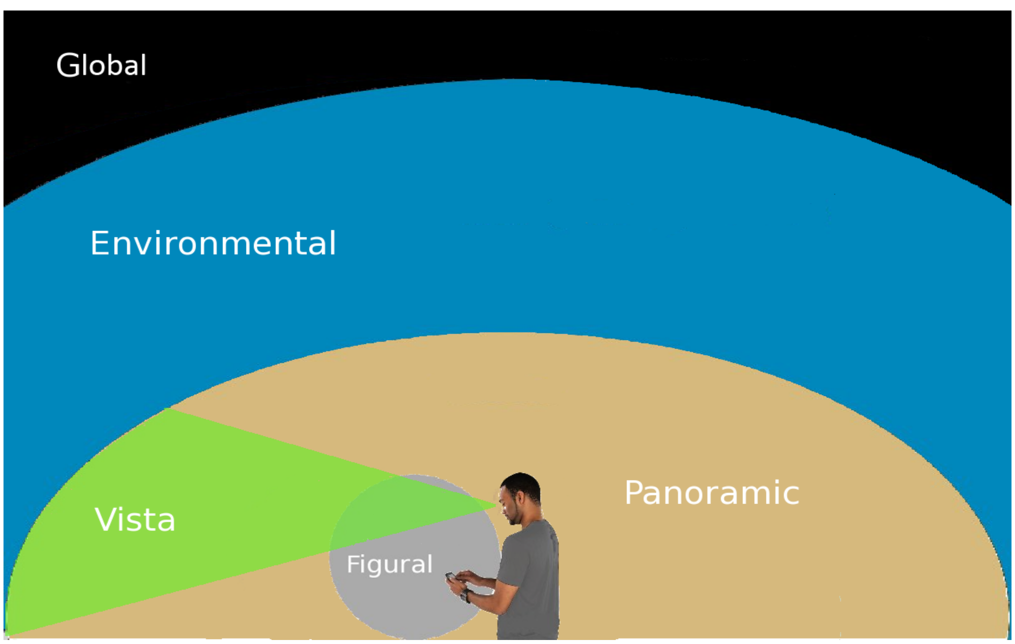

Figure 1.1 The Mixed Reality Scale Framework (MRSF)

Figural Scale - Spaces less than, or equal to, the size of the human body, and characterized by manipulation.

Panoramic Scale – Spaces as large, or larger than, the human body that can be perceived from a single location by rotating or tilting the head or body (panning and scanning).

Vista Scale – A subspace at the panoramic scale that refers to what is in view from a single position and orientation *without* rotating the body.

Environmental Scale – Spaces larger than the human body, that can only be perceived through locomotion, and therefore require the integration of information over time.

Global Scale – Spaces larger than the human body, that cannot be physically experienced and, therefore, must be represented in a map or model.

I discuss the derivation of the MRSF from the associated literature, and give specific examples of spatial scale in MR experiences as part of the related work discussed in Chapter 2. While the framework is derived from previous work in spatial cognition, primarily by researchers concerned with geographic information systems, the relevance of spatial scale in MR design and the analysis of MR experiences in the context of a framework such as the MRSF have not yet been articulated. The primary contribution of this dissertation is to begin this discussion by more fully describing how MR experiences rely on spatial scale throughout their lifetimes, in terms of design, use, and evaluation.

Using spatial scale as a sensitizing concept for a number of studies, I demonstrate the relevance and value of such an approach to the future of MR. In Chapter 2 I describe how spatial scale operates in much of the thinking and criticism of researchers in MR and related fields. I show that different research traditions tend to use scale in one of two ways. Either they focus on one particular scale (or scales), using the concept to define their object of analysis, or else they use scale implicitly and unconsciously in their analysis of MR systems, defining concepts and drawing distinctions that are inherently based on scale without realizing it. In a similar vein, Chapter 3 describes the way that spatial scale makes its way, unconsciously, into the thinking of MR designers and users. Through analysis of a number of examples of MR experiences deployed in the wild, by myself and other researchers, I show that observed and reported problems and successes of these experiences correlate to problems or successes in the use of spatial scale. Finally, in Chapter 4 I demonstrate through a case study of the campus tour how spatial scale can operate as a basis for the design and evaluation of complete MR experience. These examples suggest the benefit of a continuing research agenda surrounding the use of spatial scale in MR, and the value of the MRSF as the cornerstone of that agenda.

1.3.2 Fundamental Concepts in Multiscale Design

Having shown that evidence of spatial scale and "scale-thinking" can be seen throughout the design, use, and analysis of MR systems, and that successful use of scale correlates to qualitative observations of the effectiveness of these systems, acquiring a deeper understanding of how to use scale effectively becomes of paramount importance. A second contribution of this dissertation is to identify some of the concepts in multiscale design that can be employed in the design and analysis of MR experiences. At the core of these concepts is the notion of *continuity*, borrowed from contemporary film theory as described in Chapter 5, and refers to the way that an MR experience provides the right physical and conceptual affordances for connections to be made between and within spatial scales.

In Chapter 3 I explain how a lack of sensitivity to the role of scale in the design of the [inbox] experience resulted in a lack of continuity that was problematic for many users. A similar continuity problem also explains the observation of "placemaking" seen in a study conducted by Morrison et al. (Morrison et al, 2009). However, unlike the more general issues encountered with [inbox], that study's continuity problems, which manifest as failure of users to navigate effectively with the system, can be directly accounted for through an understanding of the *coordination of representations across scales*. That idea, derived from Distributed Cognition, not only accounts for observations made by Morrison, but also suggests that an entire category of techniques and strategies, what I refer to as *scale transitions,* should be considered central constructs in the design of any multiscale MR system. This concept, and specific instances of it, is further explored in the context of an interview study with MR designers where I show that it is embodied in a number of examples and understood implicit in the thinking of those designers. Scale transitions also figure heavily in the design and analysis of the campus tour, where it is used to both identify opportunities for design intervention during the analysis of the analog tour, and operationalized into a variety of techniques used in the MR version of the campus tour. That study also identifies the concept of *scale-matching,* in which the information being delivered to participants correlates exactly to the scale at which it is being delivered. Although this idea is more specific to MR walking tours, violations of this principle seen in that tour resulted in confusion among participants that suggests it is applicable to MR experiences more generally.

1.3.3 Techniques for Achieving Continuity

While the importance of continuity in multiscale MR experiences and the value of achieving continuity through strategies such as scale transitions and scale matching comprise general approaches and constructs useful to MR design, it is also important that we have tangible examples of these concepts in action. A third contribution of this dissertation is the collection and description of specific techniques that create or maintain continuity in MR experiences. Naturally, this is not an exhaustive list by any stretch, only a small collection that reinforces the value of the concepts I have described and seeds further investigation, and presents practical solutions to designers.

The first technique is one that was mined from the interview study, having been implemented by two of the participants. These designers were faced with the task of trying to use MR to virtually recreate real world environments that were impossible for users to traverse, either because of distance or because they no longer exist. Both these designers used a collection of panoramic spaces, high-resolution panoramas specifically, to approximate the larger-scale environment; earning this technique the name *environmental approximation*. Although all the implementations of this technique differ in some very significant ways, how a user enters or leaves a panorama, for example, these differences add to the strength of the overall approach. The basic technique of approximating an environment with multiple panoramas, and some of the consequences and affordances of doing so, is common across all these implementations and worthy of being the central concept in its own discussion.

Within a collection of panoramic spaces there is always the question of how one should navigate them. One technique that has shown tremendous versatility is what I refer to here as *panoramic sliding*. This technique can be simple or complex in its implementation, but at its core it simply provides the user with the ability to move from one panoramic space to another purely through the use of software, and usually at the touch of a button. One mainstream example of this can be seen on Google's "Streetview" application, where animations allow a user to "warp" from one panoramic location to another. The power of this technique, however, lies in how it is constrained as well as how it is implemented. Allowing for easy sliding between panoramic spaces provides the sense that these spaces are connected physically, and is therefore quite useful in environmental approximation. Conversely, limiting the ability to slide between panoramas creates the impression of distance and this can be used most effectively to give users the sense that they have left one environment or another. Furthermore, limiting sliding by certain rules, for example, only allowing slides to places the user has physically visited, help control user behavior and overall flow of an experience. Concrete examples of this technique are seen in Chapters 3 and 4, and further discussion of its potential and effects can be found in Chapter 6.

A final technique for achieving and maintaining continuity is the use of *embodied triggers* to achieve scale transitions. This term describes the mapping of physical actions, particularly those characteristic of the spatial scales discussed above, to the controls of a system. Some examples that are discussed in this dissertation are the autoloading of a panorama when a user stops within a certain bounding threshold of that panorama, the use of directional pointing to drill down into the details of an augmented object, and use of downward or upward gestures and looks to change the state of the interface or the information provided on it. Having a map slide into view when the user looks down with his device as subject #3 did in his application discussed in Chapter 3 is one example of this.

1.3.4 The MR Campus Tour and Tools

In addition to outlining essential concepts and basic strategies for multiscale design, it is also instructive to have an exemplar to refer to. The MR campus tour serves as such an exemplar, embodying the principles and techniques outlined in this dissertation into a tangible form. Moreover, this tour and its associated tools are a fully functional platform upon which to develop future projects and iterations. Although the MR campus tour is unique to Georgia Tech and dependent on the GTmob infrastructure, the tour is built from a number of components, in combination, that could be reproduced elsewhere, making it both extensible and portable as a platform for future work. The tour also implements a number of techniques for accomplishing scale transitions, a database structure and RESTful interface that facilitates both scale matching and scale transitions (described in Chapter 4), and a set of web-based tools for adding and maintaining content.

1.4 Chapter Summary

Chapter 2 - This dissertation draws on related work from cognitive science, human-computer interaction, mixed reality, and others. Chapter 2 is a dedicated related work Chapter that begins with a discussion of the growing influence of scale in the HCI and design communities, and situates fundamental work on spatial scale in cognitive science as a part of this effort, including a more in-depth discussion of the MRSF, its origins, and assumptions. The discussion then shifts to foundational frameworks of MR and AR, including: Milgram & Kishino (Milgram and Kishino, 1994), , Benford et al. (Benford et al., 1998) and McGonigal (Mcgonigal, 2006) and uncovers the underlying assumptions each of these makes in regard to spatial scale. This effectively demonstrates that spatial scale is implicit in much of this work either in defining an object of inquiry, or as factor in determining differences between systems. The final section of this Chapter uses Azuma's criteria for AR, which operates at the figural and panoramic scales, as the basis for extrapolating a broader definition of MR by identifying higher scale correlates to his original criteria. This expanded definition and the concepts that constitute it are then explored through the rest of the work.

<u>Chapter 3</u> - Chapter 3 explores the role of spatial scale in the thinking and reasoning of MR designers and users. This Chapter begins with a description of the [inbox] MR experience. Through design reflection, artifact analysis, observation, and post-experience interviews, I demonstrate that spatial scale was an unconscious factor in [inbox]'s design. Furthermore, I suggest that many of the problems [inbox]'s users experienced when participating in [inbox] resulted from their desire for better coordination between [inbox]'s scale-based elements. That problem is summarized as a lack of *continuity* between different scales and this concept serves as a basis for understanding the following sections; this lack of continuity might potentially have been mitigated by a framework like the one introduced here, and this analysis lays the groundwork for further exploration of this essential concept in multiscale design. The second study found in this Chapter is a re-analysis of the "Like Bees Around the Hive" (BeeHive) study conducted by Morrison et al. (Morrison et al., 2009). This analysis deconstructs the essential task involved in the use of their system, navigation, in terms of spatial scale and suggests that the major finding of their work "place-making" resulted from the failure of there system to provide appropriate structures to support the *coordination of representations*. In addition to suggesting better approaches to accomplishing navigation in this application I

also use this analysis to further the importance of *scale transitions* in MR applications, which are defined as specific techniques used to preserve continuity across scales. In an effort to further demonstrate the role of spatial scale as a factor in design, and identify some specific examples of scale transitions, the final section of this Chapter turns to an interview study with 3 MR designers. I show that each designer intuitively incorporated scale into his design process, and derive three scale-based techniques that can be generalized to other MR experiences. These are *environmental approximation,* in which a series of panoramas are used to approximate a larger environment; *panoramic sliding,* in which a user can move between panoramic spaces virtually; and *embodied triggers,* in which the coordination of representations is tied to physical changes in bodily orientation or locomotion. These techniques and others are then shown again in the MR campus tour discussed in the next Chapter.

<u>Chapter 4</u> – Chapter 4 deals exclusively with the campus tour and discusses analysis, implementation, and evaluation. The first section introduces the analog tour beginning with the Georgia Tech website. Through participant observation and discourse analysis of the tour experience a number of observations are made about the structure of the analog tour, and these identify either opportunities for intervention in the MR version, or aspects of the tour we want to maintain. They include the role of *scale-matching* information to the scale of the experience, the use of panoramic "stop-and-talk points," the lack of coordination in the use of written materials, and the lack of continuity in framing the experience for different classes of visitors. The second section describes the tour itself and identifies how the observations made in the first part were transferred into MR, with emphasis on the use of scale transitions discussed in Chapter 4 with the addition of two more *embodied triggers*: the autoloading of panoramas when a participant stops within range of a panorama; and the use of selecting-by-pointing to call up a more detailed information pane. The final section of this Chapter discusses the observations

made during the evaluation of the MR campus tour with 30 middle school students. These include participants coordinating representations as a means of referring to objects they were reading about, problems resulting from improper scale-matching, accessing panoramas from within a range of physical distances, and the social dynamics of users.

Chapter 5 – Chapter 5 is a discussion Chapter that focuses on moving from the primarily spatial focus of the dissertation and the MRSF to questions of place and meaning. Having established the importance of continuity across scales, the basic principles involved, and some techniques for achieving it, this discussion turns to the implications of this approach. Through close-readings of canonical texts by Tuan, Manovich, Alexander, and others, I demonstrate that place is also a multiscale concept and show how its influence is also integral to the effectiveness of the campus tour. I relate the formation of cognitive models, particularly the "walkabout" model discussed by Shore (Shore, 1996), which include both space and place to the notion of *trajectories of interaction* identified by Benford and Giannaci (Benford and Giannaci, 2010), and suggest that trajectories are also multiscale concepts. I suggest that communicating mental models at multiple scales has the potential to create continuity throughout an MR experience through the idea of *convergence,* a common concept found in the writing of all these authors. In this light, I discuss the notion of scale transitions as a means of creating convergence and preserving continuity in a manner similar to the way "cutting" preserves continuity in the visual language of film, and I suggest that these are a potential starting point for developing a similar language of MR.

Chapter 6 – This final Chapter summarizes the results of the dissertation and relates findings from the specific studies back to the hypotheses and questions introduced in Chapter 1. In addition, this Chapter also directly addresses the final question and hypothesis that the MRSF fulfills Halverson's criteria for a cognitive framework.

CHAPTER 2

RELATED WORK

All research requires the integration of numerous sources of previous work. Interdisciplinary research, by its nature, requires the integration of previous work from multiple domains, and so it should be expected that any review of related literature in interdisciplinary research is much more substantial than in traditional disciplines. In this chapter I cover a number of sources related to different aspects of the current research. First, I look at work from cognitive and psychological sciences, including cognitive geography. This work is essential in identifying the role of spatial scale in human conceptions of space, and ranges from preliminary work done decades ago to the more recent and specific work that is a direct antecedent of the MRSF. I then briefly discuss the growing importance of scale as a construct in Human Computer Interaction research, and situate spatial scale as one instance of this, contributing to this growing discourse.

The remaining sections of this chapter are then dedicated to using spatial scale as a lens for examining existing MR frameworks. The frameworks discussed demonstrate one of two influences of spatial scale on their reasoning. The first is the use of spatial scale to implicitly define the object of inquiry. In other words, they use scale as means of defining what MR is and is not. The other tendency is to use spatial scale to differentiate between types of MR, and identify different features of different systems. Both of these uses are implicit however, showing that spatial scale is an unconscious factor influencing the thinking of researchers in this field. The final section of this chapter attempts to build a bridge between different conceptions of MR that operate on distinct scales to create a definition of MR using features common at every scale. This definition and the features it identifies are then used throughout the remainder of the dissertation.

2.1 Scale in Cognition

Spatial scale as an object of inquiry, or as a cognitive and design construct, does not have a very clear intellectual lineage. The formative work of Ittleson (Ittelson, 1970, Ittelson, 1973) who, in 1973, presented a distinction between awareness and interaction in spaces smaller than the human body and those in spaces larger than the human body, is perhaps the earliest example of dividing spatial cognition into scales, using embodied boundaries. He concluded that distinctly different cognitive skills are needed to understand spaces, objects, and interactions at these different levels, which he defined as "object" versus "environmental" cognition. Since that time, some work has been done in the cognitive sciences to identify and measure specific abilities at different scales.

For a number of decades now, a branch of cognitive science has been examining the relationship between scales of representation (and human interactions with them) and specific cognitive abilities. Building on Ittleson's original distinction between environmental and object spaces, those cognitive scientists have postulated four competing models to help explain how spatial abilities and scale might be related. Hegarty et al. (Hegarty et al., 2006) summarize these as:

> Unitary Model - cognitive abilities are the same at both "large" and "small" scales.
>
> Total Dissociation Model – cognitive abilities are completely distinct between small and large scales.
>
> Partial Dissociation Model – some cognitive abilities are the same at large and small scales, while others differ.
>
> Mediation Model – cognitive abilities are distinct at large and small scales, but have a common "mediating" variable.

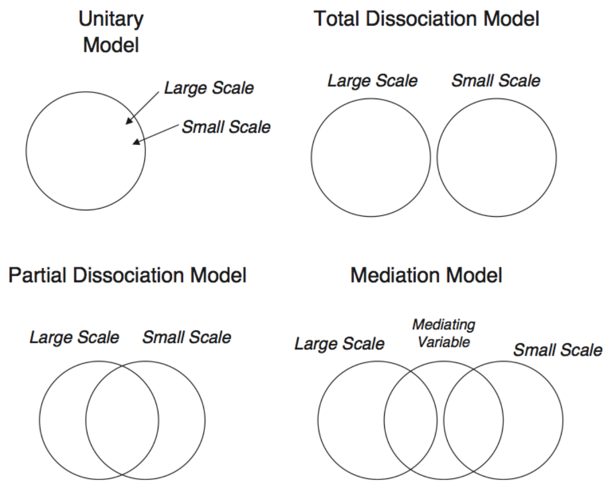

Figure 2.1. Four models of scale abilities and spatial cognition. Reproduced from Hegarty, 2006.

To date, research has produced little evidence in support of the Unitary and Total Dissociation Models, as some spatial abilities have been demonstrated on both large and small scales, while others appear to be distinct to one particular scale or other. Furthermore, while the Partial Dissociation and Mediation Models cannot be ruled out as easily, there is little evidence to support any particular mediating variable as more valid than any other, and so the Partial Dissociation Model has come to the forefront. However, while this model can help us correlate certain cognitive abilities with either large or small spatial scales, (distance estimation, directional pointing, etc.) the basic division between spaces larger than the body and those smaller than the body is only a first order approximation of how humans differentiate between experiences at different spatial scales. There is some overlap in the skills people use to make sense of large and small spaces; presumably, this has some correlation to different internal representations of space that are themselves the likely result of bodily experience as well as symbolic factors. Unfortunately, the types of skills that are typically examined in these studies are what I would describe as "procedural" skills, such as distance estimation, or path planning. These abilities are likely to be valuable ones for understanding spatial experiences, but they lack any explicit connection to the higher-level cognitive abilities, such as meaning-making. The processes involved in meaning-making, and how these relate to spatial abilities have been shown to be quite varied among different cultures, and these cultural differences can also affect the lower-level mechanics of spatial cognition as well (Shore, 1996, Hutchins, 1996). MR applications involve higher-level spatial abilities as well as lower ones, and this implies that any theory of meaning-making for MR must be able to explain how these seemingly separate cognitive processes might be connected together a topic I take up in chapter 6.

2.1.1 Narrative Accounts of Scale

The psychologist, Barbara Tversky, has analyzed accounts of individuals providing verbal "tours" of their living spaces, as a way of examining how people narrativize spaces (Tversky, 2004) and the verbalizations of these perspectives seem to correlate directly to the scales of the MRSF. Her research notes three different perspectives subjects used when providing these accounts. The first is what she describes as a "route perspective" in which the subject "describes each successive object or room from the traveler's changing viewpoint." An account of this type takes the listener or reader on a journey through the space, and involves a position that changes over time. In this way it reveals an internal model of the space that is at the environmental scale, essentially a trajectory through an environment.

A second style revealed in Tversky's research is what she terms a "survey view." In this style, the speakers describe the environment from a stationary viewpoint above it, effectively reducing the entire environment into a figural scale internal representation, a cognitive map that is narrativized by the subjects. The third style Tversky describes as a hybrid of the other two styles. The "gaze perspective," as she calls it, describes spatial relationships relative to the observer as in a route perspective, but with a stationary point of view, as in a survey perspective, a combination that is consistent with a panoramic view of the space.

2.2 Scale in HCI

Recently, a number of HCI researchers have been using scale as a sensitizing and organizing concept for theorizing, designing, and evaluating human-computer interaction. For example, LeDantec et al. (LeDantec and Edwards, 2010) use scale as a means of demarcating levels of influence and accountability in the hierarchical organization of social services in the public sector. Subsequently, they have built technological interventions that operate across these scales to alter the power structure inherent to such organizations. Dourish (Dourish, 2010) identifies the tension between the global and local scales found in Pepper's critique of environmental utopianism (Pepper, 2007) as a potential locus for technological intervention. He suggests using technologies to create networks of individuals through aggregating common human-scale actions as a means of forming strategic alliances to affect larger-scale social change. For example, if users of a social networking site were able to see who else is interested in purchasing a specific item, reading about a certain topic, or attending a similar event across a wide range of geographic locations and socioeconomic classes, it becomes much easier to organize these individuals into a collective that could potentially influence corporate or government organizations. He refers to this as the potential for "scale-making."

In a similar vein, Laurel's notion of Gaian IxD (Laurel, 2011), a reimagining of Lovelock's "Gaia hypothesis" (the earth as a single living organism) (Lovelock and Giffin, 1969), presents a new perspective on interaction design which acknowledges "complex interrelated systems at all levels of scale." Like Dourish, she argues for this new approach to interaction design in order to help connect individual user actions and experiences with products and services to the larger social structures that determine how, when, where, and what kind of interactions are possible. Notably, that same publication presents Shneiderman's (Shneiderman, 2011) thoughts on the distinction between Micro-HCI, which he locates at the level of the user interface, and Macro-HCI, which involves investigating opportunities for the integration of HCI into higher-scale human endeavors such as commerce, law, health, education, etc. These efforts, although largely preliminary, demonstrate that scale can be successfully employed to organize concepts that are potentially valuable constructs in the design and analysis of computational systems and our interactions with them. I would add spatial scale to this growing discourse on more general uses of scale in HCI as yet another way that this sensitizing concept can foster new approaches to understanding interaction with computational systems.

2.3 The Origins of the MRSF

Many different taxonomies of spatial scale exist in cognitive geography literature. The MRSF is a modified hybrid of the frameworks derived by Montello (Montello, 1993) and Freundschuh & Egenhoferfer (Freundschuh and Egenhofer, 1997). Montello's framework consists of four categories of scale, making it among the simpler conceptions. Notably, each of his scales can be correlated to specific positions, movements, and actions of the human body; defining the experience of space in terms of embodied cognition, and connecting this framework to work on embodiment in both cognitive science (Lakoff and Johnson, 1980) and human-computer interaction. Montello offers the following description of his framework:

> *Figural* space is projectively smaller than the body; its properties may be directly perceived from one place without appreciable locomotion. It may be usefully subdivided into *pictorial* and *object* spaces, the former referring to small flat spaces and the latter to small 3-D spaces. Figural space is the space of pictures, small objects, distant landmarks, and the like. Although one may sometimes haptically manipulate (touch) objects to apprehend their spatial properties, no appreciable movement of the entire body is required.
>
> *Vista* space is projectively as large or larger than the body but can be visually apprehended from a single place without appreciable locomotion. It is the space of single rooms, town squares, small valleys, and horizons.
>
> *Environmental* space is projectively larger than the body and surrounds it. It is in fact too large and otherwise obscured to apprehend directly without considerable locomotion, and is thus usually thought to require the integration of information over significant periods of time. It is the space of buildings, neighborhoods, and cities. Although environmental spaces cannot be apprehended in brief time periods, I maintain that their spatial properties can be apprehended from direct experience alone, given enough exposure to them.
>
> *Geographical* space is projectively much larger than the body and cannot be apprehended directly through locomotion; rather, it must be learned via symbolic representations such as maps or models that essentially reduce the geographical space to figural space. This bears repeating: Maps represent environmental and geographic spaces, but are themselves instances of pictorial space! I therefore expect the psychological study of map use to draw directly on the psychology of pictorial space rather than on the psychology of environmental space. States, countries, and the solar system are good examples of geographical spaces (not withstanding the earth-bound reference in the word *geographic*). The surface of the earth as seen from an airplane, however, would constitute a vista space because of its

(Montello, 1993 pp. 315-316)

Freundschuh and Egenhofer's taxonomy, on the other hand, summarizes seventeen different schemes for classifying scale cognition in the context of Geographical Information Systems (GISs). They compare and contrast models of spatial cognition, including Montello's, and distill a framework that identifies the common elements of *manipulability*, *locomotion*, and *size* as the fundamental building blocks of all these different models of scale spatial perception. Using these three factors in various combinations they arrive at their own model of spatial experience consisting of six categories with the following characteristics:

(1) *Manipulable object space* comprises very small, manipulable spaces that do not require locomotion to experience them. They comprise objects smaller than the human body. Models that include this kind of space refer to it as object (Canter, Ittelson), personal (Kolars and Nystuen), small-scale (Downs and Stea, Mandler), physical (Pinxten et al), *A* (Zubin), haptic (Mark), and figural (Montello) space.

(2) *Non-manipulable object space* consists of non-manipulable, small spaces requiring locomotion to experience them. These include objects larger than the human body and typically smaller than house-size spaces (e.g., cars, elephants, trees). Models that include this space refer to it as object (Ittelson, Canter), living/working (Kolars and Nystuen), small- (Garling and Golledge, Siegel), and medium-scale (Mandler), as well as *B* (Zubin) space.

(3) *Environmental space* includes non-manipulable, large spaces that require locomotion to experience them. These include inside-of-house spaces, neighborhoods, to city-size spaces. All of the models reviewed include this space, referring to it as districts and spatial regions (Lynch), neighborhood and city/hinterland spaces (Kolars and Nystuen), medium- (Garling and Golledge) and large-scale (Downs and Stea, Garling and Golledge, Ittelson, Mandler, Siegel) spaces, places (Canter) and local scope (Muehrcke and Muehrcke), sociogeographic (Pinxten et al), *D* (Zubin), transperceptual (Mark), and environmental (Montello) spaces.

(4) *Geographic space* covers very large, non-manipulable spaces that due to practical limitations cannot be experienced via locomotion. These include larger than city-size spaces, states, countries, and the universe. Models that include these spaces refer to them as small- (Siegel) and large-scale (Ittelson) space, regional/national space (Kolars and Nystuen), global scope (Muehrcke and Muehrcke, Kolars and Nystuen), cosmological (Pinxten et al), and geographic (Montello) space.

(5) *Panoramic space* encompasses non-manipulable, small- to large-size spaces that do not require locomotion to experience them. These include views in a room, an auditorium, a field, and from a scenic overlook. Models that include this kind of space refer to them as spatial nodes (Lynch), C-space (Zubin), pictorial space (Mark), and vistas (Montello).

(6) *Map space* represents non-manipulable, small- and large-size spaces that do not require locomotion to experience them. Maps are a symbolic representation, whose general intent is to reduce and simplify spatial information and present it in a manageable form. Maps are the result of the cartographic generalization process. Although several of the reviewed models make mention of maps and point out their unique space-in-space property, none have an explicit type of space equivalent to how map space has been defined here.

(Freundshuh & Egenhofer, pp. 371-372)

Notably, the category of "Non-manipulable Object Space" does not appear in the MRSF, the reasons for this are described in Appendix A.

2.3.1 The Mixed Reality Scale Framework

Here, I turn to the MRSF itself and discuss aspects of previous work that it includes as well as rejects and provide specific examples of MR experiences at each of the scales with some discussion of their critical attributes.

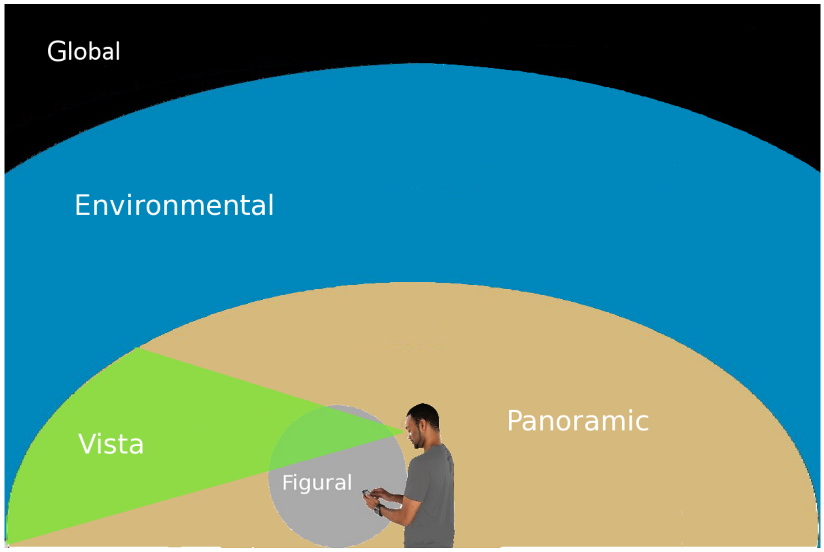

Figure 2.2. The MRSF

2.3.2 Figural Scale

At the lowest level, the *figural scale*, the space can be viewed in its entirety from a single position and is experienced through the act of manipulation. Montello further subdivides this space into "pictoral" or 2D and "object" or 3D spaces, and these might be typified as "maps" and "models," respectively. As noted in Montello's description of *geographic scale*, the only way to apprehend geographic space is through some figural scale representation, a 2D map or a 3D model. Freundschuh & Egenhofer, also acknowledge this point, and give "map space" its own category in their taxonomy of scale spaces. Maps also necessarily simplify information from larger spaces in order to serve as cognitive aids. The choice of what to include or exclude in these projections, has political as well as cognitive connotations, and these are discussed often by media theorists such as de Certeau (De Certeau, 1984).

The figural scale of MR experiences is likely the most well explored area of MR. The reason being that the most widely available, and easiest to use, technology up to this point has relied on the use of trackable fiducial markers to correctly register virtual content into the world. These markers themselves are, almost universally, figural scale objects, and so the virtual objects and 3D worlds mapped onto them are naturally figural scale as well. In many of these examples, an entire virtual environment is mapped into the figural space.

Figure 2.3 Levelhead.

The game "Levelhead," developed by Julian Oliver, uses some particularly interesting applications of scale. In this game, which is described by the creator as, "A 3D Spatial Memory Game," the player must twist and tilt a cube to move an animated character from a predefined "entrance" to an "exit." It is essentially a 3D maze. Each face of the cube represents a single room that has a number of doorways for entering and exiting, as well as a number of obstacles such as walls and stairs. Although the original version uses just one cube with six rooms, later versions use three cubes for a total of eighteen rooms, creating a more complex puzzle. What makes the game novel is that AR technology is used to "map" the various 3D rooms onto the individual faces of the cube, creating the appearance that each face of the cube corresponds to an entirely different and overlapping volumetric space.

Viewing this MR experience through the lens of spatial scale we can see first that the experience has all the elements that we would expect at the figural scale. The entire AR world is contained on a tabletop and therefore viewable from a single position, and the mode of interaction is manipulation; the player rotates and tilts the cube on the tabletop. The most interesting aspect of Levelhead though is the choice of representations it uses. While the experience occurs at the figural scale, the representations used on the faces of the cubes are at the panoramic scale when imagined from the perspective of the player's avatar. Similarly, the 3D environment of Levelhead is a summation of these panoramas; a collection of rooms with relationships between them that require locomotion of the avatar in order to perceive them as a whole. Thus, solving the puzzle requires the player to construct an internal representation that connects these various spaces together, an internal representation of environmental space. Such a representation is often referred to as a *cognitive map* (Kaplan, 1973, Kitchin, 1994).

Levelhead is also a "map," (although "model" is more technically correct) in the sense that it is a projection of a larger scale space, the panoramic scale of the rooms, into a smaller scale space, the volume of the cube. Levelhead could easily have been accomplished with purely figural representations, a marble rolling through connected boxes for example. However, Oliver's choice to use the metaphor of navigating through a building taps into other cognitive abilities related to experiences of space at different scales. One possible strategy for navigating Levelhead, that we can infer from this analysis, would be for the player to internally adopt the perspective of the avatar and imagine walking through the maze in the first person. Although no study of Levelhead has been done to determine if this strategy is used, perspective-taking is considered one possible "mediating variable" in the coordination of action across spatial scales (Hegarty et al., 2006).

2.3.3 Panoramic Scale and Vistas

In Montello's original conception he does not distinguish between the immediately surrounding space, and the section or slice of that space which is currently visible in any given orientation. I have relabeled this scale *panoramic*, using the term and definition from Freundschuh & Egenhofer, and reserved the term "vista" for a subspace of this scale that is essentially a currently visible slice of the panoramic space. Freundschuh & Egenhofer derive the category of "panoramic" space based on elements common to many of the definitions they assemble in their taxonomy. Still, panoramic space is identical to Montello's conception of the vista scale, however, for our application to MR, conceiving of a vista as a subspace is more productive for two reasons. First, MR is largely visual in nature and while panoramic space and vista space are essentially of the same scale, panoramic space is NOT visible in its entirety from any position. Instead to experience a panoramic space an observer must rotate their body or head to "scan" the world, effectively integrating numerous views into one continuous space. Yet, at any given time, only a segment of this space is visible. We need a term to describe this currently visible space, and a "vista" serves this purpose nicely. Second, "panorama" is a specific MR technique that can be used to create a virtual space that surrounds the user, but is often independent of his position (only rotation or orientation matters). This makes the adoption of Freundschuh & Egenhofer's category even more apt, as in correlates exactly to a known MR technique. Thus, while panoramic scale spaces as I have defined them here, require changes in orientation and integration of spatial information from memory over time, vista spaces do not require either. Furthermore, the imagined integration of multiple vistas can be used to construct an internal representation of a panoramic space, much the same way that individual photographs can be "stitched" together to create a panorama. This point suggests an immediate correlation between internal mental operations and computational ones that is potentially useful.

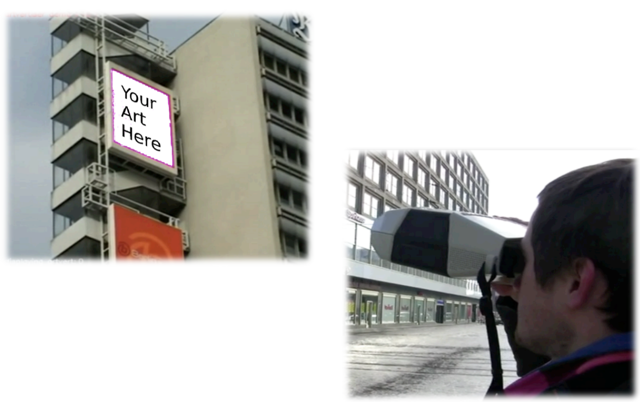

Figure 2.4 The Artvertiser.

Another of Julian Oliver's projects, The Artvertiser[1], created in collaboration with Clara Boj, and Diego Diaz is a good example of a panoramic AR experience. A user views the hybrid space through a device that resembles a high-tech pair of binoculars. A computer in the device uses a computer vision algorithm to detect the sharp corners and rectangles that typically define a billboard or poster advertisement. Once an advertisement is within view, the system selects an image from an onboard database and inserts it over the advertisement. The Artvertiser was created as a way to give consumers more control over their environment. As the authors claim, it transforms the "read-only" spaces of billboards into "read-write" spaces. While the political ramifications of this are interesting, and the potential to "rent your eyes" to artists and advertisers is a compelling business model, it also has interesting implications when analyzed in terms of scale.

The Artvertiser is a panoramic scale AR application, as the entire experience can be viewed from one location and the primary means of observing the space is through "scanning." However, it might be rightly classified as a vista experience, because the virtual content is limited to what is currently in view. The underlying technology of The Artvertiser only selects *bounded* segments of the surrounding space as isolated areas for augmentation. One never has the impression that a single augmentation extends beyond the current view, the virtual space of The Artvertiser is discrete and much more like the fiducial marker tracking described in the section above. However, the idea that content from one view might be conceptually related to content in another view is very much still a possibility for The Artvertiser and systems like it. The Artvertiser underscores the point that the role of *boundaries* between spatial scales is an important one, particularly in MR experiences where such boundaries can be created through virtual representations as well as physical ones. How users recognize what is, and is not, part of an MR experience; how relationships between disjoint areas or representations are connected; and how these experiences are engaged and disengaged, turned off and on, need to be considered when

[1] http://theartvertiser.com/

creating immersive interactive MR experiences. Moreover, boundaries need not be purely physical, they can be symbolic or conceptual as well making the experience of boundaries more conceptual and indirect.

Although they occur at the same spatial scale, “panoramas” created with a different technology, the Argon AR Browser[2], offer a more immersive panoramic scale MR experience than The Artvertiser. Panoramas created with this system are essentially a collection of perspective-adjusted images placed to form a box (akin to the skybox used in video game design) around the user. As figure 2.5 illustrates, these spaces are continuous areas of virtual content that completely surround the user, and require scanning to perceive completely. Only a vista can be viewed at one time and, with current consumer technology, only through a small “window” created by the screen of a handheld device. Figure 2.5 is taken from a MR tour of the Georgia Tech campus (discussed in Chapter 4) and the role of the panorama shown here is to provide a “virtual tour stop” that allows the user to experience a space that they would otherwise not have access to on the physical tour, the inside of the football stadium. Creatively manipulating these kinds of immersive panoramas in different contexts seems to be one of the foundations of building MR experiences with the current generation of technology and features heavily in the campus tour experience described in chapter 4.

Figure 2.5. Handheld Panorama.

[2] http://www.argon.gatech.edu/

2.3.4 Environmental Space

Where figural and panoramic spaces can both be apprehended from one position, environmental spaces require locomotion to experience them, and this is their defining characteristic. What panoramic and environmental spaces have in common, however, is that both surround the human body and therefore require the summation or integration of spatial information over time. The implication is that different internal representations, mental models with different features for example, are required to interact at different scales. Furthermore, where embodied cognition suggests that internal models are at least partially the result of unconscious processes associated with positioning, and moving the body in space, the individual actions of manipulation, scanning, and locomotion are likely to activate different internal models. The fact that these activities are tied to specific spatial scales lends significant weight to the MRSF as a good candidate for understanding the connection between internal and external representations in the construction of MR spaces.

Human beings are only capable of seeing what is directly in front of them, objects and places that are out of view exist only in memory as symbols and sense impressions. Regardless of whether content persists visually, it is still a component of the user's experience of the space, as part of their internal representation of that space, and is available again with a glance in the right direction. Because environmental scale experiences combine the physical and virtual in ways that are not wholly visual, the emphasis naturally shifts to methods and techniques needed to construct coherent internal representations of the hybrid spaces, and so environmental space tends to rely more on indirect or symbolic cognitive processing.

Figure 2.6. Can You See Me Now?

The game Can You See Me Now? (CYSMN) (Benford et al., 2006) is a good example of an environmental scale MR experience. In the game, which is essentially a game of “tag,” online players access a virtual model of a real city, although the usable playspace is limited to a 500x1000 meter area. Online players can move through the model using the computer keyboard. “Runners” in the physical world move throughout the real city and their GPS locations are updated in real time within the virtual model so online players can see the location of the runners chasing them. Likewise, runners have an interactive map on their handheld device that shows their location and that of the players they are chasing.

Although CYSMN involves representations at numerous scales, (runners can stop and look around to get a panoramic view, or look at the figural space of their handheld) just as natural experience does, the mapping of virtual and physical spaces occurs at the environmental scale. The physical environment of the runners and the virtual environment of the online players are combined to create a hybrid space that frames the actions of both categories of participants. This hybrid space exists only as an internal representation, a cognitive map, in the minds of the players and runners, and its boundaries are purely symbolic. Externally, only fragments of relevant information are perceptible. An avatar represents the runner’s position in the online virtual world, and the GPS coordinates represent the location of the online player in the real world. Apart from suggesting that MR environments can exist as shared representations across a number of individuals, CYSMN also brings up issues surrounding what bits of information from higher scales can and should be represented in lower scales. Deciding what forms these should take, and understanding how they are coordinated together to facilitate the creation of good cognitive maps, is going to be of paramount importance for understanding and building future environmental scale MR experiences.

2.3.5 Geographic Scale as Global Scope

Both Montello and Freundshuh & Egenhofer identify geographic scale spaces as the topmost level in their taxonomies of spatial scale. In both conceptions these spaces are understood to be so large that they cannot be conceived of without the aid of some symbolic representation, as in a map or model. The need to reduce such spaces to the figural scale, as all authors suggest, also removes the need for a specific psychology of geographic space, as these spaces are now subsumed into the figural (and potentially panoramic) categories. However, the related work of Muehrcke & Muehrcke (Muehrcke and Muehrcke, 1992) and that of Kolars & Nystuen (Kolars and Nystuen, 1975), suggest another conception of geographic space that is directly relevant to conceptions of scale in MR.

While Muehrcke & Muehrcke are concerned with maps and cartography specifically, they draw a distinction between maps that are *local scope* and those that are *global scope*; a distinction that hinges on the level of reduction in the size of the space as it is projected onto the map. Larger reductions, on the order of 1:100,000 for example, mean that a much larger geographic area is being represented on the map, and maps of this size fall under the category of "global scope." Smaller reductions, 1:25,000 for example, mean that a smaller geographic area is represented on the same size map and are termed "local scope." Rightly, Freundshuh & Egenhofer observe that there are no "established boundaries" between these very relative terms, with the area between

1:25000 and 1:100000, being particularly problematic. Map users must rely on their own internal conceptions of these spatial boundaries, and these vary across individuals and cultures. Rather than dwell on this ambiguity, however, I want to focus on the terms themselves. The notions of global scope and local scope are terms that have been used in computer science to define the "namespaces" in which a variable can be accessed. Variables with local scope are only available to the functions and blocks of code in which they are defined. In contrast, variables that have global scope are accessible by all the functions and subroutines of a program. This is an essentially hierarchical relationship, just like the one used in the MRSF, and, as a metaphor, it suggests that *global scale* elements, defined as those that are accessible to scales below, is a good starting point for reinventing the notion of geographic scale used by Montello and Freundshuh & Egenhofer, in more MR-friendly terms. The question of just what it means for these elements to be accessible to lower scales is a necessary one to answer.

Citing the research of Kolars & Nystuen, Freundshuh & Egenhofer give us a good indication of how this global relationship might work:

> Kolars and Nystuen (1975) provide a hierarchy of geographic space that is defined by the level of interaction among people and between people and the environment surrounding them. Scale is an important consideration in this hierarchy as scale influences the spatial behavior of individuals and any interpretations made about specific behaviors.
>
> (Freundshuh & Egenhofer, p.366)

There are three important notes to make about this statement. First, the notion that geographic space can be defined, not by inherent qualities of spaces themselves, but by the "level of interaction among people and between people and the environment" suggests that such spaces are defined: socially, culturally, and politically. Second, the statement that "scale influences spatial behavior" furthers the notion of scale as a socio-cultural context for action and interaction, and indicates that this context is likely to manifest itself behaviorally, and therefore encompasses some cognitive elements related to behavior. Mental models are a likely candidate here, as they have been shown to have behavioral effects (Gentner et al., 2001, Johnson-Laird, 1983). The final point is that not only does scale influence behavior, it also affects the "interpretations" of those behaviors, and therefore serves to contextualize action. Taken together, these three ideas point to a notion of global scale spaces that, in addition to referring to large spatial regions, also organizes socio-cultural interaction and has very distinct cognitive components of "behavior" and "interpretation." Where MR is specifically concerned, the notion of a *global scale* allows us to bring a previously unrelated branch of scholarship surrounding Alternate Reality Games (ARGS) into the mix and integrate that research more directly into the discourse surrounding MR. This is the first step toward using the MRSF as unifying framework for MR design across multiple disciplines, academic traditions, and work-styles and is explored more thoroughly below.

2.4 Scale in Existing MR Frameworks

The MR walking tour that is the subject of this dissertation is a multiscale experience. That is, it requires coordination between elements that exist at all the scales of the MRSF. To achieve this coordination, and to properly situate it in relation to other MR experiences, we need a framework that places equal emphasis on the physical and visual elements found at the figural and panoramic scales, with the conceptual elements of experience that dominate the environmental and global scales. This presents a problem for existing conceptions of MR because they tend to emphasize lower-scale elements or higher-scale elements, but not both. To support the claim that the MRSF is capable of integrating these disparate views, this chapter first reviews existing conceptions of MR and explicates their use of spatial scale. Because the human experience of space, that all MR mediates, requires different cognitive faculties at different scales, designing for and analyzing that experience requires different methods, units of analysis, and theoretical frameworks. Understanding these differences as differences of scale helps designers and researchers know which body of work to draw from when building and analyzing their experiences, and how to properly situate their work, particularly multiscale work, within the discourses of the different communities that work in mixed reality.

If it is the case, as I have argue here, that spatial scale is an essential feature of the thought processes surrounding Mixed Reality than we should expect to see evidence of it in the ways that researchers discuss MR. In both academic and mainstream discussion, MR experiences are known by a number of different names, with Augmented Reality (AR), Mixed Reality (MR), Alternate Reality (AR), and Mediated Reality (MR) being the four most common. Regardless of name, these experiences all share the common feature of mixing real and virtual elements; yet, they all do so in significantly different ways. For example, Augmented Reality tends to rely on mixing virtual graphics into a scene of the physical world. Examples of this can be seen in the various forms of tabletop AR applications (Andersen et al., 2004, Barba et al., 2009, Xu et al., 2008), "utility" applications such as Layar[3] or Yelp[4] , research experiments such as those done for location based gaming (Benford et al., 2004, Morrison et al., 2009), or in-situ visualization (White and Feiner, 2009). At the other end of the spectrum, Alternate Reality Games (ARGs) attempt to create a virtual context (typically a narrative) for actions in the real world, creating a mix of realities at a much more conceptual and symbolic level. For example *World Without Oil* (Mcgonigal, 2006*)* asked participants to live their everyday lives as if the price of oil had reached previously unheard of highs, giving ordinary activities new meaning in the virtual context.

Making these distinctions even more pronounced is the fact that the terminology is often not used consistently. Some researchers use the terms Augmented Reality and Mixed Reality interchangeably, to refer to the same class of experiences in which the immediately visible environment is graphically altered, a technique others refer to as Mediated Reality (Mann, 1994). However, other researchers use the term Augmented

[3] http://www.layar.com/
[4] http://www.yelp.com/

Reality to refer to experiences and artifacts that mix realities in a way that is more consistent with approaches in mobile and ubiquitous computing. AR, in this context, provides a way to bridge physical and virtual representations, or new ways to interact with data (Mackay, 1998). Still others use Mixed Reality to refer to experiences that mix real and virtual elements both visually and conceptually to create rich and complex environments for interaction (Benford et al., 2006, Macintyre et al., 2004). Such a broad range of experiences, approaches, and technologies perhaps necessarily requires some versatility in the language needed to describe them. Researchers and practitioners should be free to adopt the terms that best suit their work, and this often means terms specific to a discipline, a genre (such as games), or one appropriate for the goals of the project. However, as I demonstrate here through close reading of canonical texts defining those differing conceptions of MR, the major distinctions between them can be understood entirely through their different uses and approaches to spatial scale. I will show that not only is scale-thinking evident in the ways that researchers define their object of inquiry and situate their research, but it is also a potential source of similarity between different research areas and approaches.

2.4.1 Milgram, Kishino and the Virtuality Continuum

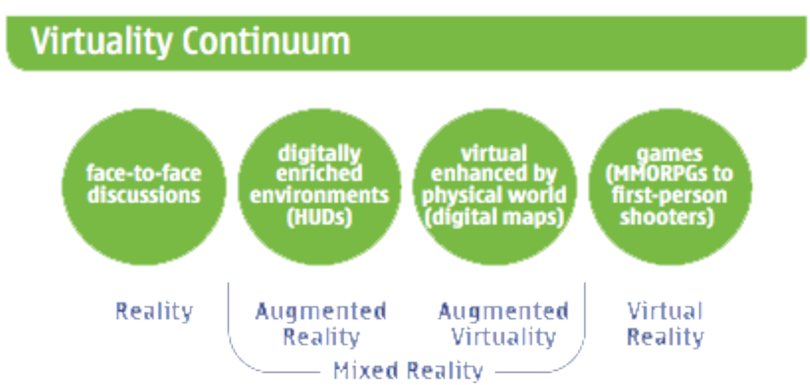

Figure 2.7 Virtuality Continuum

An oft-cited definition of MR was published by Milgram and Kishino in 1994, and defines MR in terms of a "virtuality continuum" (Milgram and Kishino, 1994). The continuum consists of combinations of real and virtual elements (mixed in different proportions), excluding only purely physical and purely virtual realities at either end of the spectrum. This definition, however, was formulated at a time when mobile computing was in its infancy and Virtual Reality (VR) was still in vogue, and therefore could not anticipate the paradigm-shifting growth in mobile computing seen in the last decade. It therefore inherits some of the assumptions about the future and nature of computing common to that era. In particular, it focuses heavily on the use of head-worn, 3D, display technologies (e.g., video see-through, optical see-through, etc.) to mix virtual content with the user's view of the world around them. Furthermore, it classifies MR based on different ways of visually and spatially mixing physical and virtual content using those displays.

This adherence to visual display technology is tied to the concept of spatial scale in a very predictable way. The lower level scales, figural and panoramic, in which visual experience dominates over the conceptual are the only ones considered in Milgram & Kishino's analysis. Environmental and Global scales, which frame and structure spatial experience from the top down, do not come into play, and the value of internal representation is of much less concern than the external representations viewed on displays. For Milgram & Kishino, spatial scale implicitly defines their approach to MR and their object of inquiry.

2.4.2 Augmented Reality as Ubiquitous Computing

In 1998, Mackay offered an alternative notion of Augmented Reality (Mackay, 1998), one that focused on the user experience rather than the visual display. While her view attempts to encompass some of the same kinds of AR that can be found in the MR continuum, it also includes other categories of AR as well. Augmenting the environment, or objects in the environment, to make them networked and interactive is seen as a workable alternative to relying on user-equipped displays. This is somewhat closer to mobile MR in its current incarnation, as it involves various forms of broadband networking that are the backbone of content delivery in mobile systems. These techniques include things like networked paper and other "smart" objects, as well as algorithmic analysis of video from real-time camera feeds and other sensor data. In this tradition, AR was understood to denote technologies that took everyday objects and activities and enhanced them in some way. Making activities more collaborative or more personalized, and giving objects memory or awareness, were all ways of "augmenting" user experiences.

Not surprisingly, this definition also reflects the dominant mode of thinking at the time of its inception. As the VR vision of computing that informed Milgram & Kishino's work was fading into the background, a new vision of Ubiquitous Computing (UbiComp), offered by Weiser (Weiser, 1991), was taking its place. This view was, in many ways, the antithesis of the VR view. Instead of inserting ourselves into the virtual world of the computer, UbiComp had us inserting computers into everything around us. UbiComp saw the world as a rich environment of hidden information and capabilities, waiting to be made available to us, and responding to our needs, both hidden and obvious. It is clear now that neither of these visions for the future of computing have come to pass, at least not in their extreme versions. Mass-market technology has evolved quite differently from what was imagined by researchers a decade ago. Instead of donning head-worn displays, gloves, and other sensors to enter virtual worlds, or walking through interactive forests filled with smarter versions of everyday objects, the sensing apparatus and computing power has been compressed into the smartphone, and the intelligence of the environment is piped in "on-demand" from the vast data and processing facilities of the cloud.

2.4.3 Mixed Reality Boundaries

One additional view of MR, offered by Benford et al. (Benford et al., 1998, Koleva et al., 2000), stems from the use of mixed and augmented reality for telepresence applications and so is rooted in Computer-Supported Cooperative Work (CSCW). It uses a number of the same concepts inherent to the MRSF, including the notions of "framing" and "boundaries." This view also has a complex relationship to Milgram & Kishino's virtuality continuum, and functions as a classification system as well. Benford et al.'s notion first provides a classification scheme for a wide range of computer-mediated collaborative experiences that would all fit their definition of MR, these include "media-spaces, spatial video-conferencing, CVEs (collaborative virtual environments), telepresence applications, and collaborative augmented environments." Their classification system is a typical 3-axis system with the dimensions of *transportation*, *artificiality*, and *spatiality*. They describe each as follows:

> Transportation concerns the degree to which users are transported into some new space or remain in their local space. Artificiality concerns the degree to which the shared space is based on real-world information or is synthesized. Spatiality concerns the degree to which the shared space exhibits key spatial properties such as **containment**, **topology**, **movement**, and a **shared frame of reference**.
>
> (Benford et al., 1998 p. 218)

Artificiality and transportation are less related to the current discussion, and can in fact be largely reduced to categories already present in Milgram & Kishino's taxonomy. At present, I want to focus on *spatiality.* It is interesting to note that the authors discuss the concepts of *artificiality* and *transportation* for a combined total of 4 pages, while the third concept, *spatiality* is given 4 pages of its own, twice as much as each of the other concepts. This suggests that spatiality is the most important or, perhaps the most difficult, of these concepts to understand. The fact that spatiality is given such weight in their discussion is also evident in the fact that, unlike artificiality and transportation, it is unique to MR. The author's also make this point:

> Unlike the previous two dimensions, that might potentially be applied to CSCW systems in general, spatiality (obviously) applies specifically to the kinds of shared-space system discussed in this article.
>
> (Benford et al., 1998 p. 195)

Benford et al.'s conception of spatiality emphasizes the combination of multiple spaces into one shared space, as is typical of telepresence applications. They give a more detailed description:

> A further dimension that may be used to characterize shared-space systems is their degree of spatiality. This concerns their level of support for fundamental physical spatial properties such as containment, topology, distance, orientation, and movement as shown in Figure 3. Its extremes are characterized by the notions of place, a containing context for participants; and space, a context that further provides a consistent, navigable, and shared spatial frame of reference.
>
> (Benford et al., 1998 p. 195)

They discuss spatiality in the context of a number of archetypal examples, of which simple video-conferencing is the first.

Benford et al. claim that video-conferencing has very little spatiality, and so can be found on one end of what they term the "spatiality scale" (much like the virtuality continuum but not to be confused with spatial scale) where there is only "place" ("a containing context") but not "space" or dimension. The participants all agree they are in a conference (the place) but there is no space other than the bounded squares of each participant's camera. They claim this demonstrates the principle of *containment*. In terms of the MRSF this is a global scale experience, a fact that is revealed in the notion of "place." All members of a video-conference agree that are in the video conference, a point that Benford et al. suggest creates a dimensionless place without space. Yet, one needs a space to assemble the multiple camera feeds that define a video conference, and so, unlike an audio-only conference call, those camera feeds must have some kind of visual-spatial representation. Therefore, some space must exist. The point that all the separate spaces captured by different video cameras do not assemble cleanly together to create a new seamless shared space is, I believe, what those authors mean when they suggest that video conferencing lacks space and specifically that it lacks a "shared frame of reference." However, a shared frame of reference that provides a context for interpretation rather than purely for physical interaction is a hallmark of global scale MR, and so it is clear that video-conferencing involves some higher order cognitive framing. The MRSF is consistent with this understanding, as the global frame accounts for the placeness the authors describe. In both conceptions, place is a frame of mind.

A second project discussed by Benford et al. is the Clearboard project (Ishii and Kobayashi, 1992). Their point in mentioning this project is that it adds some "dimension" to basic video conferencing, moving closer to space and further from place by allowing users to see each other's drawings on a desktop surface. Thus Clearboard shows how the addition of topology (akin to surface features here) can help create shared spaces.

Figure 2.8 – Clearboard

Clearboard provides users with the ability to draw on the same surface that displays video from a remote camera. Benford et al. classify the spatiality of Clearboard as exhibiting both containment (an enclosing space for video) and topology (surface features to manipulate). Clearboard involves manipulation and is also about as large as the human body, so fits the criteria for figural space.

A further improvement on video-conferencing Benford et al. attribute to the Hydra project (Sellen et al., 1992) (Figure 2.9). In this system each video-conference participant has a physical “surrogate” (monitor/camera/speaker unit) that is arranged in a ring that mimics a conference room setting. Hydra demonstrates adding *orientation* to achieve spatiality, every unit has its own orientation and therefore its own view and spatial relationship to the other units. Interestingly, the original evaluation of Hydra showed that users of this system preferred to arrange the surrogates so that all are simultaneously visible. The Hydra authors describe the “stretching” and “warping” of space that occurs with this system as users put all the surrogates in front of them. In terms of the MRSF we might also describe a similar warping effect as compressing the information in a panoramic space into a vista space. Essentially, users of Hydra preferred to use the system in a vista configuration rather than a wholly panoramic one.

Figure 1. *A user is seated in front of three Hydra units. Each Hydra unit contains a video monitor, camera, and loudspeaker.*

Figure 2.9 Image and caption of Hydra System (Sellen et al., 1992)

A further system, used to demonstrate the concept of a “shared spatial frame of reference,” is the MAJIC system (Ichikawa et al., 1995), which is a pure panoramic space in terms of the MRSF. In this system each location has an identical curved screen and desk. Users sit at each of the desks, while the screen shows an image of all the participants assembled into one combined virtual space. In this way the system creates the impression that the participants are all in the same hybrid space together. This hybrid space is what Benford et al. refer to as a shared spatial frame of reference, a set of Cartesian coordinates that everyone shares. Yet, this system also has a limited range of movement, you cannot enter and walk around the other participants regions of the shared space, and this fact, the authors' claim distinguishes it from other "fully spatial systems" such as "3D collaborative virtual environments" and "shared augmented reality systems." Those systems allow participants to fully move around and explore the environments and use representations of other participants' avatars, to depict their positions and orientations, and are what I would term environmental scale MR systems.

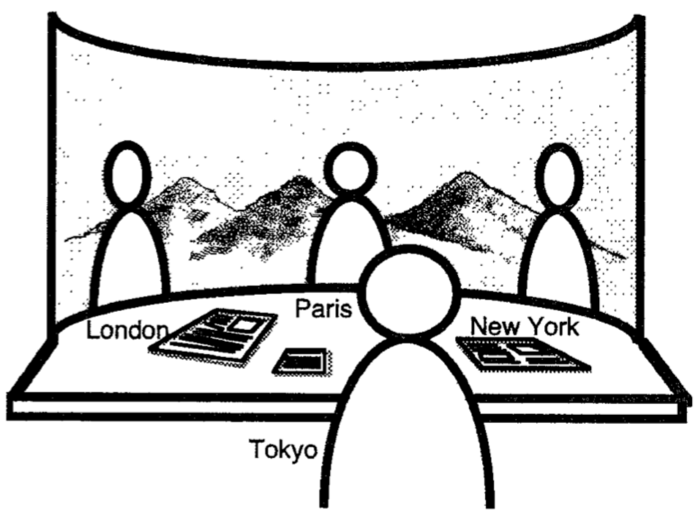

Figure 1: The first draft of MAJIC.

Figure 2.10 Image and caption from MAJIC (Ichikawa et al., 1995)

This discussion of examples from Mixed Reality Boundaries demonstrates how the differences in telepresence applications observed by the authors, differences upon which they base the categories of spatiality (containment, topology, distance, orientation, and movement), correspond almost exactly to the embodied characteristics inherent to the scales of the MRSF. This gives further weight to the power of the MRSF to accurately describe the world in the correct language, as well as to its application as a classification system for MR experiences and as a unifying framework for the various conceptions of MR that have been around for more than two decades. Most importantly though, it shows that spatial scale is an inherent part of how researchers and designers think and reason about MR spaces, and suggests that making this notion explicit and using it in system design is worthy of continued investigation.

2.4.4 Cognitive Immersion in ARGs

Reflecting on a presentation she gave at Collective Play (McGonigal, 2003b) McGonigal offers our final conception of Mixed Reality:

> Pervasive play, I explained, consists of "mixed reality" games that use mobile, ubiquitous and embedded digital technologies to create virtual playing fields in everyday spaces. Immersive games, I continued, are a form of pervasive play distinguished by the added element of their (somewhat infamous) "This is not a game" rhetoric. They do everything in their power to erase game boundaries – physical, temporal and social — and to obscure the metacommunications that might otherwise announce, "This is play."
>
> (McGonigal, 2003a) pp. 1-2)

In her view, Alternate Reality Games, which are exemplars of "immersive games" are a special subclass of pervasive play. The purpose of these games, according to McGonigal, is to proliferate play throughout the physical world by establishing an alternative context for actions and activities in which potentially any object, place, or person has significance within the frame of the game, this is the Mixed Reality she is referring to.

For McGonigal, the critical element of MR is *cognitive immersion.* ARGs are designed to erase all boundaries between the everyday world and the mixed reality of the game. In ARGs, the game narrative serves the function of recontextualizing everyday experiences and real-world artifacts. This idea, combined with the fact that ARGs are played simultaneously by hundreds of players across the globe for periods of time on the order of months rather than weeks, suggest that they are an archetypal example of mixed reality at the global scale. A similar point is made by Benford et al. (Benford et al., 2006) in their description of *performance frames* in the context of a city-wide Mixed Reality game (Uncle Roy All Around You, URAY).

2.5 Azuma's Augmented Reality and Bridging the Gap

The striking difference in the approaches and definitions of MR discussed above are often attributed to differences in technology. The more display-centric conceptions require purpose-built technology to achieve augmentation, while the higher-scale approach of ARGs relies on technologies already embedded in the world. However, there is more to it than that. They also differ in their approach to human experience particularly where aspects of cognition are involved. ARGs rely on purely symbolic and conceptual cognitive processes to achieve their effects, while more traditional forms of MR focus on somatic experience. As I have said, the MR walking tour is multiscale in nature and requires that both of these approaches be merged to support the somatic and symbolic cognitive processes that are required to make those experiences meaningful. Fortunately, the gap between these is not insurmountable. As a way to bridge this divide I begin with the definition of augmented reality offered by Azuma, (Azuma, 1997), which primarily concerns somatic experience, and correlate that conception to a number of important constructs in higher order symbolic thinking. The result is a set of features that define MR at every scale and that can help us evaluate a multiscale experience with the same criteria.

Soon after Milgram & Kishino contributed their definition of MR, Azuma provided a simple and specific definition for Augmented Reality (AR)). For him, AR denoted interactive spaces created through the 3D registration of computer-generated imagery with a user's view of the physical world around them. His definition came in three parts that reflected this view:

1. Combines the real and virtual
2. Interactive in real time

3. Registered in 3D

Going back to Milgram & Kishino, AR has been understood as a subset of MR, rather than a wholly separate field, and so Azuma's framework contains many of the same assumptions, including the reliance on visual sensing and display and a unit of analysis that focuses at the figural and panoramic scales. Still, Azuma's framework does more closely address the interactive elements of AR and provides a useful starting point for helping us bridge the gap between small-scale, visually focused MR, and the larger-scale conceptually focused MR that appears in other conceptions.

Mapping Physical and Virtual

The first of Azuma's criteria, combining the real and virtual, is the most basic element of all MR experiences, and is straightforward, on its surface. Unfortunately, specific definitions of "real" and "virtual" are hard to come by, leaving the boundaries of MR open to interpretation. To avoid getting into an extended philosophical discussion I consider "real" to be synonymous with "physical," and related to objects and environments that can be perceived without any technological mediation. Virtual elements then, are simply those elements that exist primarily as digital information, and can only be accessed and represented through information and communications technologies (ICTs). Usually, this requires some mode of representation of the information that puts it into a form that can be perceived and understood by a user.

The question of how physical and virtual elements are combined is the subject of Milgram & Kishino's continuum. At one end of the spectrum, virtual elements are added visually into a physical scene, creating the familiar configuration of AR. At the other end of the spectrum, physical elements are placed into a virtual scene, creating the less well-known concept of Augmented Virtuality (AV). As is the case with any continuum, there are varying degrees of combining physical and virtual elements that constitute the middle of the spectrum. This conception suggests the notion that hybrid realities are created through process of "mapping" (Lakoff and Johnson, 1980) or "blending" (Fauconnier and

Turner, 2003). In the case of AR, virtual elements are mapped into physical reality, and in the case of AV, physical elements are mapped into a virtual reality.

In Lakoff & Johnson's conception of mapping, humans form "image schemas" through bodily experience that then serve as the basis for understanding new experiences and abstract concepts. During the mapping process a source domain (such as an image schema) is used to determine how the structure and relationships in the target domain are interpreted. Different aspects of the target domain will be emphasized or hidden, depending on the source domain used. In the often-cited examples of LOVE IS WAR and LOVE IS A JOURNEY different source domains are used to generate different models of the target domain (love). In this way the source acts to shape the interpretation of the target. The process of mapping is an internal, symbolic one, and is considered to be a fundamental operation of human cognition. This idea works as a bridge between the somatic and symbolic and allows us to frame and interrogate issues of cognition within the realm of MR experiences while maintaining our focus on the combination of real and virtual elements. Where lower-scale somatic MR focuses on the mapping of *external* physical and virtual representations. Higher-scale MR maps *internal* representations, in the sense that it us used in cognitive science. This can be seen quite clearly in ARGS where a "virtual" representation of the surrounding narrative is completely internal and serves as the source for interpreting the meaning of action in the physical world. This same idea is also relevant to "registration" and is discussed further below.

Embodied Interaction

The second criterion, that AR be interactive in real time, involves two ideas that need to be expanded when considering MR, "interaction" and "real time." While HCI offers many theories and frameworks to choose from, I focus primarily on the idea of "embodiment," identified by Dourish (Dourish, 2001), as it already has close ties to the notion of "embodied cognition" that from which the idea of mapping discussed above is derived. This fits with Merleau-Ponty's (Merleau-Ponty, 2004) phenomenological notion of embodied experience, as the primary means by which people make sense of the world. Additionally, it calls to mind Lakoff & Johnson's influential ideas around embodied cognition, which posit, among other things, that cognition is structured through bodily experience in the world, although shaped and colored by cultural conventions, a point that will become integral to our discussion of the design of MR tourism experiences.

There is a natural connection between interaction discussed by Azuma in the idea that interaction occurs at multiple scales and requires different cognitive processes at those scales, we simply need to acknowledge it. Each of the scales of the MRSF corresponds to a different embodied experience, a different "core mechanic" for interaction at that scale: manipulation, scanning, walking. For Azuma, interaction occurs at all scales without distinction. By acknowledging that interaction is qualitatively different at different scales we can preserve the somatic basis for MR while also incorporating higher-scale conceptual elements.

Real Time(s)

In addition to the concept of "interaction," the second part of Azuma's second criterion, "real time," also needs to be expanded when considering MR more broadly. Where Azuma intended for the term to denote immediate, observable changes in the state of the system, much as the term is used in HCI, a broader conception might allow for systems whose changes occur over extended time periods. Time, of course, operates on a number of scales ranging from the imperceptibly small computations of a microprocessor, to the imperceptibly large changes of geologic time. These are all "real" time frames. Although the extreme ends of this continuum might not be relevant to MR (or any mediated) experiences, a range of interaction times on the order of seconds, minutes, hours, or months, which are directly perceptible in human experience, must all be considered in a broader conception of MR. Such timeframes also correspond strongly to the various scales of space contained in the MRSF. Larger timeframes on the order of weeks or months are more characteristic of global scale, shorter timeframes such as seconds and minutes are more relevant to figural and panoramic spaces, and environmental scales typically fill the gap in-between, on the order of an hour or two. These are less precise than the boundaries of space, but are good general guidelines.

2.5.1 Registered Frames of Reference

Azuma's final criterion, 3D registration, is perhaps the most constitutive of AR experiences. While most computer systems combine real and virtual elements that users interact with in real timeframes, most are not registered in 3D.

3D registration is a 3-dimensional version of "image registration," which refers to the process of combining multiple images taken in different coordinate systems (typically different cameras, lenses, or positions) into one unified coordinate system (see (Zitova, 2003) for a complete discussion). In the case of AR, instead of 2D images, we are typically discussing 3D spaces and models, and while all the objects being registered need not be 3D objects themselves, the final space does need to appear as if it is rendered in 3D (even if it is then projected onto a 2D screen). This is somewhat confusing for novices, and this part of Azuma's definition reflects the underlying techno-centric view that has been pervasive in AR research.

There is another way of conceiving of registration that, while no less complicated, is perhaps more intuitive. The essence of registration is that data from one or more *frames of reference* are mapped into one unified frame of reference. This can be done either by transforming one to fit the other, or by transforming both into a third, hybrid frame. Essentially, this is a more abstract way of describing the mapping or blending of the real and virtual that was discussed above; these terms are also the ones often used to describe stages or techniques of 2D or 3D registration. Typically, when talking about registration, *frames of reference* are taken to be synonymous with *coordinate systems*. This is a mathematical interpretation of the term, and is appropriate given the mathematical operations needed to register two objects into one frame of reference. However, frames of reference can be understood more broadly as elements of cognition (particularly spatial cognition) and reveal themselves in linguistic and cognitive artifacts as well as mathematics. Adopting this larger view of frames of reference allows us to both expand our understanding of registration from small-scale MR into large-scale MR and to maintain its prominence in the definition of these systems.

The application of frames of reference as a cognitive mechanism for interpreting action is largely owed to Bateson (Bateson, 1973), who noted that "framing" was the means by which play behaviors are distinguished from identical non-play behaviors. In Bateson's conception, establishing "play" as the frame of reference colors the interpretation and meaning of all actions and behaviors that follow. A typical example is found in the play of dogs. When dogs play, their actions are the same as when they are fighting. Yet, once a play frame is established, these actions are not interpreted as threatening. Not surprisingly, framing has also been studied in regard to MR gaming and performance (Benford et al., 2006), and so application of this concept to MR experience more broadly, is not without precedent. Additionally, the sociologist Erving Goffman, takes the notion of framing one step further in his development of "frame analysis" (Goffman, 1974), and applies it to a wider range of human activities outside of play, specifically to "everyday life," (Goffman, 1959). He suggests, like Bateson, that framing is a foundational cognitive process responsible for organizing experience into meaningful categories.

2.6 Summary: Solidifying a Multiscale Definition of MR

At this point we can give a reasonable working definition of Mixed Reality grounded in the very clear and concise definition of AR given by Azuma. From this discussion we could summarize MR as having the following elements:

- mapped
- embodied

- spatial
- temporal
- framed

For those who prefer a more traditional definition we might say:

> Mixed Reality maps physical and virtual elements into a hybrid frame of reference that mediates interactions in time and space.

While neither form is perfect, they both accomplish the important goal of allowing us to consider both physical and conceptual human experiences, at distinctly different scales, as part of the family of MR experiences. This definition and, more particularly, the set of 5 features will be used throughout this work to ground our analysis of different MR systems and the multiscale MR campus tour by acting as touchstones for understanding how MR operates at individual scales.

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CHAPTER 3

SCALE-THINKING IN THE DESIGN OF MR EXPERIENCES

3.1 Introduction

I have taken the position that scale is integral to the ways that human beings experience and make sense of physical space. In the previous chapter I demonstrated how this unconscious perception appears to have influenced researchers in MR. Here, I argue that this unconscious partitioning of space is also essential to how designers and users make sense of MR experiences. If this is indeed the case, one would expect to see evidence of scale-thinking in a few places. First, artifacts themselves should have clear evidence of spatial scale. If we assume that designers have the intention of making their MR experiences meaningful to users, then we would expect that they draw on conceptions of space they believe to be intuitive. This need not be intentioned, and in many cases designers are not even aware enough of their own conceptions of space to consciously build these into their experiences. Instead, what we would expect is that designers simply build what is intuitive to them with the belief that it will also be intuitive to their participants because it draws on some common experience of space. Currently, whether these attempts are successful or not is totally dependent on the skill and intuition of the designer about what will work and what will not work in regard to the user experience. However, that situation is less than ideal, particularly if we wish to teach people how to best design and build effective MR experiences. A more explicit framework of spatial experience that designers can employ when creating and evaluating their MR experiences would help take some of the guesswork out of building these systems by providing conceptual tools and strategies that have been shown to effectively account for problems and provide solutions inherent to MR design. I argue that the MRSF is such a framework, and this chapter demonstrates its ability to provide insights useful for MR design through analysis of the role of scale-thinking in the design and use of MR systems.

The next section of this chapter discusses [inbox] an immersive MR experience designed to introduce participants to the shipping container system. [inbox] was not designed with scale in mind, but spatial scale nonetheless is evident in its implementation. Reflection on the successes and shortcomings of [inbox] suggest that a more intentioned use of scale might have led to a more productive and accessible experience. One observation taken from post-experience interviews suggests that a major source of confusion for [inbox] users was a lack of *continuity* across the different scales of the experience. Building on this idea, the next section discussed scale in the context of navigation application and shows that one major problem with this application was its failure to provide for continuity across scales as well, particularly in the specific task of *coordination of representations*. As an attempt to find repeatable solutions for preserving continuity across scales the third section of this chapter uses interview studies to uncover the unconscious use of scale in other MR applications. A number of techniques and categories to preserve continuity are unearthed in this study. These include the idea of *scale transitions,* which are techniques used to change content and representations when the user moves to a different scale, as well as *embodied triggers* as one sub-class of these transitions, and the notion of *environmental approximation* which describes the increasingly common use of collections of panoramas linked together to approximate a much larger environment.

3.2 [inbox] with Malcom

[inbox] is an immersive MR experience that takes place inside of a 20-foot ISO (International Standards Organization) shipping container. The project was developed over 3 months and appeared under the category of "Art Installation" in 2009 as part of the ACM Creativity and Cognition Conference (Barba et al., 2009). [inbox], as it was

originally conceived, is described in the proceedings of that event (Barba et al., 2009), however, the final product of 3 months of design differs significantly from the original conception and so I will first describe the final version of the project here, before discussing the design decisions and processes which led to the changes seen in the final result. The first five sub-sections below describe the experience of [inbox], its goals, motivations, and the cultural issues it attempts to address. The subsequent sections describe the role of spatial scale in both the design and use of [inbox], and demonstrate the innate use of scale in the design of individual elements of the project, as well as how these related to some of the issues [inbox] encountered when participants were attempting to make sense of their experience.

Figure 3.1. a.) 20' shipping container. b.) Interior of [inbox].

3.2.1 [inbox] from start to finish

Approaching the installation, visitors find a full-size 20x8x8-foot shipping container in a parking lot (figure 3.1a). Through the open door, a large map is visible on the back wall of the container, and the other interactive elements, a slideshow and life-size mannequin seated at a desk, are visible on opposite sides of the interior (figure 3.1b).

Before entering the container, participants are given a Gizmondo handheld device and a pair of headphones. They are instructed to press the play button on the device to begin the audio narration as they enter the container.

Through the audio narration, participants are greeted by Malcom McLean, the inventor of the container and modern shipping system, represented physically by a mannequin seated at a desk (figure 3.2). Background audio, in the form of a continuous loop of sounds sampled from various sites along the container's journey through shipyards, railroads, and highways plays through loudspeakers in the container itself. This ambient soundtrack can still be heard faintly despite the headphones. The narrator, voiced by an actor portraying Malcom, invites participants to listen to the story of how he came to invent the container system, while they investigate a projected slideshow that "[he] has put together." The slideshow consists of projected pictures of real shipping containers, which have been embedded in AR frame-markers (a frame-marker allows images to be placed inside a trackable frame border). These allow participants to use the Gizmondo to access AR image overlays depicting historical times and places from Malcom's story (figure 3.3).

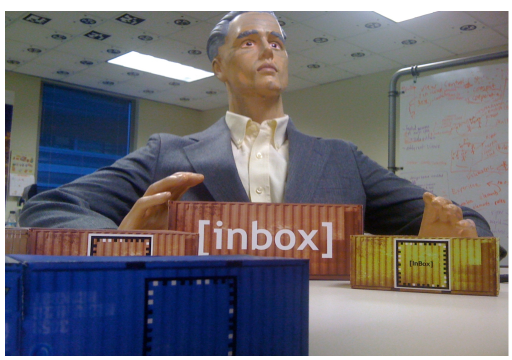

Figure 3.2. Malcom mannequin seated at his desk with AR enabled miniatures

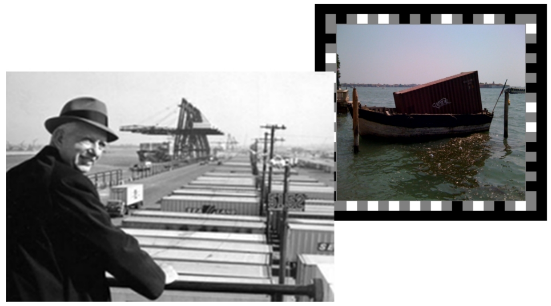

Figure 3.3. Example of marker slide with AR overlay.

After Malcom has given the participants the background story of the container, he asks them to search the large map, which can be found on the back wall, for items he has hidden there. The map represents major shipping sea-lane routes from the world's largest container ports, and is also embedded with AR frame-markers (Figure 3.4). The AR content visible on the map shows the most exported goods at each container port, and includes goods such as paper, oil, and electronics. Malcom then instructs the participants to choose one export they feel they cannot live without, and capture it using the Gizmondo by pressing the stop button on the device. As with all the instructions, these are also printed on the screen. As participants bring each marker on the map into view, a cartoon depiction of an item is shown as an overlay, and audio specifically related to the manufacture, transport, or use of that good is heard through the headphones.

Upon collecting an item from the map, participants trigger an additional audio segment in which Malcom instructs them to bring their selected export over to his desk and place it into his "inbox." Malcom's desk is littered with miniature scale models of shipping containers in various sizes and colors, each with its own AR frame marker (see figure 3.4). Each miniature container displays an image of a common desk item, such as an "inbox," pencil, and globe, when viewed through the Gizmondo. Once the participants find the AR "inbox" miniature container and deposit their chosen export by pressing the stop button on their device, they are able to view their export, as if it is standing in the inbox, through the display on their handheld.

At this point, Malcom notes that the removal of an item from a container makes room for new cargo. He states, "the system must keep things moving." He asks the participant to help him see into the future to find out what that container is being used for now. Participants are instructed to return to the port where they chose to remove an export good and bring him the new cargo. Upon returning to the map, participants discover that the AR overlay at this port has changed – and an image of the most exported *illegal* good is now visible. Illegal exports include things like drugs, weapons, and slaves. After participants complete this task, Malcom thanks them for their part in making his system a success and says goodbye. Upon exiting the container, the visitor is given a cut-and-fold paper model of a miniature shipping container, along with a written message from Malcom, and an AR sticker similar to the ones used on the map.

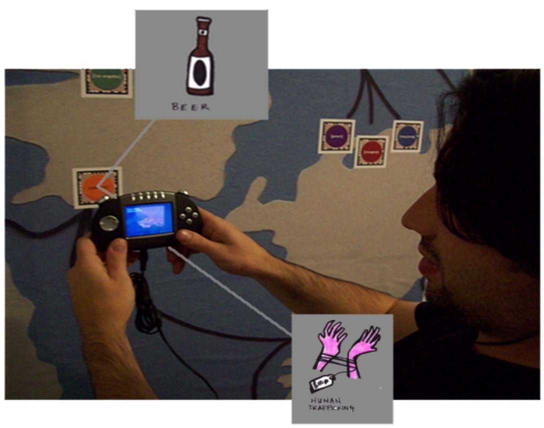

Figure 3.4. Participant revealing representations of legal and illegal exports.

3.2.2 The Container Box

To emphasize the pervasiveness of the shipping container we chose to include several different representations of it in our installation. These included the real full-size 20x8-foot shipping container that housed the installation, 35mm slide projections of pictures of containers, and miniature models of containers. All of these different representations have distinct qualities and occur at different scales. This was not a conscious decision on our part, each simply seemed to be the best way we could think of to communicate the various aspects of the container system and its effects. The container itself is a panoramic space, one that encases the participant and bounds their experience on all sides. The decision was made to set the installation inside a real shipping container because we felt an actual container had a “placeness” that could not be easily simulated. Despite its ubiquity and our dependence on it, most people have never seen the inside of a shipping container. We took advantage of this lack of familiarity and leveraged the novelty of being inside one of these containers to spark the curiosity and interest of participants. Being inside a container spatially connected them to an actual container for the first time, reducing the physical and cognitive distance between participants and the container system. This prompted many participants to question why they had never been inside a container before, as well as the assumptions they had about them. For example, nearly all the participants remarked on their experience using some variation of the phrase, “*I never realized…*” in regard to some aspect of the container, such as its size, construction, or climate. This phrase suggests that participants were not just acquiring new knowledge, but questioning why it was something they had not been aware of before.

Depending on the individual’s experience and personal interests, the simple act of setting foot inside the container prompts him to consider some of its specific attributes that interest him. An engineer might consider its construction materials and support structures, a journalist might consider what was in the container before and what stories it could tell, etc. As a point of introduction to the experience, walking into a container for the first time sensitizes participants to whatever attributes are of personal interest to them, and stimulates them to look for instances of these in other parts of the installation. The container as a setting provides the global scale framing for the experience.

3.2.3 Malcom's Desk

Unlike the average office desk, Malcom's has no physical office materials. Instead, his desk is strewn with miniature models of shipping containers of various sizes and colors, ranging in length from about 2 inches to 10 inches (see figure 3.2). Each miniature container has a frame-marker on one side, allowing participants to access an AR overlay cartoon image of typical office supplies, such as a pencil, a globe, and his "inbox." Malcom's desk is a figural space, cluttered with numerous manipulable objects; a fact that we leveraged in a number of ways.

The philosopher Bachelard (Bachelard, 1994) summarizes the powerful effects of miniaturization, saying *"The cleverer I am at miniaturizing the world, the better I posses it."* To the participant who is attentively listening to Malcom telling his story over their headphones, and interested in him as a character or historical persona, the life-size mannequin depicting Malcom McLean seated at a desk of miniature containers illustrates his supposed power and mastery over the system he created. The physical depiction of Malcom is reminiscent of the way that a state leader or military commander might be shown at a map table with model battleships. The relationship between Malcom and his creation gives the impression that Malcom is a "larger-than-life" figure when compared to the system he created. That a whole system can be contained and played with on the surface of Malcom's desk implies ease and lack of complications, in much the same way that Malcom's invention itself reduced the difficulty and complexity of transporting cargo.

When interactively engaging with the miniatures, participants can not only get a sense of Malcom's relationship to the system, but also get to experience it for themselves. Bachelard posits that the form of the miniature itself invites daydreaming and imagination. The practical, real-world problems of full-scale objects are not present, and the person interacting with the miniature is given more facility and control than with the full-scale object. These miniatures are reminiscent of toy train or building sets, and participants can have the same kind of play experience with these that they had as children playing with toys. With or without their device, they can push closer to these miniatures in the physical space, and inspect them at various angles. They can pick them up and twist and turn them in their hands. They can stack and reconfigure them on the desk. This last point is particularly interesting from an AR standpoint, in that participants can chose to rearrange these items based on either their physical or virtual characteristics. For example, stacking smaller containers on top of larger ones focuses on the physical affordances of the container and, is essentially the same process used in the transport of full-sized containers on ships, trains and trucks around the world. In this way users are, unconsciously reinforcing, through their actions, one of the practices that is essential to the success of the container system.

However, when viewing these miniatures with their device the stacking behavior takes on a new context and layer of meaning. The addition of AR forces participants to confront conflicting sets of affordances, creating a tension between the containers themselves and the items "inside" of them. Stacking the containers representing the pencil or globe on top of the one representing the desk blotter can recreate what might be viewed as a typical arrangement found on an office desk. This relationship demonstrates one of the key benefits of containerization; namely, that the transport of goods is no longer constrained by the forms of the goods themselves. Goods can be rearranged and reconfigured based on the properties of the containers they are in, rather than the properties of the goods. This is yet another essential characteristic of containerization and represents a significant advance in the transportation of cargo.

To the participant who is sensitive to political and social values embedded in technologies, the design of Malcom's desk calls attention to a continuing theme of the installation: the ubiquity of the container system and our reliance on it for consumer goods. Using their device to access the AR overlays tied to the miniatures gives the participant the impression that they can magically peer inside the container itself. Doing so reveals common everyday desk items and underscores the notion that most of the artifacts commonly found in everyday activities are available only because of our global dependence on the container system. Common desk items like pencils and clocks are often made cheaply in remote parts of the world and transported using the container system. This fact is also reinforced during other parts of Malcom's narrative when he explains how his system has opened new markets and makes products and processes available in parts of the world where they otherwise would not be.

3.2.4 Slideshow

Just beyond Malcom's desk, on the opposite wall, is an AR-enabled slideshow. The images being projected are a collection of 25 actual photos of shipping containers taken "in the wild." Each picture was taken by one of the designers or a remote participant who joined Malcom's Facebook page. All the pictures are embedded inside individual AR frame-markers, like the ones used elsewhere in the installation, and are projected for 30 seconds each within a continuous loop. Although small and tightly bounded by frame markers, the slideshow functions primarily as a vista space. This is both due to the style of the participant's interaction with it, they simply look at it, as well as what is depicted in the frames (pictures of containers and places). The rigidity of the vista, which is only accessible when looking directly at it, imparts a certain kind of experience on the participant described in more detail below.

Like all the elements in the installation, the slideshow serves many purposes and has many layers of meanings depending on what the participant is "tuning into." As with the mannequin and desk, it helps to create a deeper sense of Malcom as a character and his role in reinventing the transportation of cargo. We characterized Malcom as a grandfatherly figure, who has assembled slides of his various adventures that he forces his guests to view in extended sessions. This is a familiar character trait that evolved along with the adoption of slide projection as a technology, and is particularly prevalent in members of Malcom’s generation. In his narration, Malcom specifically mentions that he has *“prepared a slideshow [he is] sure they will enjoy*.” The AR overlays seen in the slideshow provide historical context for the installation. They depict the times, places and events in Malcom’s story. Images of the town in which he grew up, the first container ship, the dockyards, longshoremen, etc., are all tied to specific markers.

Where interactions surrounding Malcom’s desk take advantage of the cognitive elements related to the figural scale to affect a sense of power and control, viewing the slideshow is an act of passivity. This underscores yet another aspect of the container system–its lack of centralized control. This fact is a direct contradiction to the myth of inventor as master and creator embodied in the design of Malcom’s desk, and creates a contrast that highlights the multiple meanings and layers contained within the system. This loss of control is echoed during Malcom’s narrative when he asserts “*Years ago I set a system in motion, now its grown to a size I can’t even imagine.”*

When viewed without the device, the incessant repetition of image after image of shipping containers helps sensitize participants to the widespread presence of the container and the myriad spaces these containers occupy in the world around us. This can be interpreted in two ways. On the one hand, the similarity between the individual images of the containers, coupled with the fact that some repeat within the sequence itself, makes it difficult to tell one from the other or determine where the sequence begins and ends. Without the ability to distinguish one container image from the next the participant gets a sense of being overwhelmed by the uncontrollable continuous stream of passing containers. Watching the slideshow without augmentation speaks to the ubiquity and modularity of the container. Each image is so similar that they are completely interchangeable; a point which reinforces the standardization that the container system brought to the shipping industry. On the other hand, although each container is basically the same, they all have different details that mark individual histories. Participants can choose to see these images as indications of the blandness of standardization or, somewhat more optimistically, focus on the details that differentiate these containers from each other as evidence that individualism and identity are still present despite this standardization. As with all the elements of the installation, the final interpretation is left to the participant.

The addition of AR content creates a historical context for interpreting these images; a *then/now* relationship between the physical images and the AR images. The AR overlays depict landscapes, people and practices involved with the transportation of cargo before the invention of the shipping container. The practices, places, and people depicted no longer exist because of containerization. The semi-transparent ghostlike quality of the overlays let the participant see what has been lost through standardization; particularly the work practices of the longshoremen and the uniqueness and "local-color" of the landscapes. Imposing images of the past in the same hybrid space as images of the present suggests that one has replaced the other and that any changes are direct effects of containerization rather than purely historical documentation.

Whether the participant looks at the augmentations through the window on their device or just views the projected container images, the slides progress at regular intervals in a continuous and incessant loop. This presentation is, of course, reminiscent of the container system in its present form, as well as its evolution. As time passes the system continues on in an endless global loop. Containers move from place to place, and travel across the globe incessantly. In the context of the historical AR slides, the constant progression of images highlights the evolution of cargo transport and the constant march of progress.

3.2.5 Map

The largest physical element in the installation is a map representing major shipping container ports and sea-lane routes. This map was simplified and highly stylized, to reflect the characterization we developed for Malcom Mclean. For this reason, graphic design for the large-scale map was inspired by commercial graphic design of theme park maps and travel brochures from the 1960s. As an additional twist, we chose to represent the globe in "polar projection" rather than the more typical Mercator projections used in most commercially available maps. This serves to defamiliarize (Bell et al., 2005) participants with the image of the earth, and requires a moment's reflection to ascertain their orientation to the representation of the world.

Maps, as I have repeatedly mentioned, have a special distinction of being figural scale representations of a global or environmental scale space. Yet, they largely draw on the cognitive processes related to the figural scale. In language similar to what he uses when discussing miniaturization, de Certeau (De Certeau, 1984) explains that a map is a natural medium for storytelling. He claims, "*All maps tell stories, of movement through territories, imperialism and discovery, or mastery over vastness reduced to one page.*" All of these ideas could also be applied to the container system itself, and reflect various points of view on its practical and political effects that we wanted to communicate in the installation. These assertions, particularly the last one, are also implicitly about scale and in a similar vein to the previous discussion about miniaturization. The map presents a view of the container system at yet another scale. While miniaturization emphasized a familiarity with the individual container itself, the map focuses more explicitly on the interconnectedness of the system as a whole, allowing participants to view its most prominent interconnections at one time. Viewed without the device, the map icons show only the names of the major ports and the shipping lanes that connect them, not the actual cities. This again underscores the fact that there is little civil or political control over the container system. It is a global system with its own economy, leadership, and laws. It is commerce without geopolitical boundaries.

At first approach, the AR overlays found on the map simply show images of the labeled ports. Like the images of the containers shown in the slideshow, these are all strikingly similar, yet subtly different, and so much of the same analysis given above applies to these representations. The machinery and artifacts are all standardized, but the ways theses technological artifacts are situated in the surrounding landscape are unique and reflect local values to some extent.

At the point in the narrative where Malcom directs the participant to the map, the software changes the AR overlays to cheerful, cartoon-style images of the most common exports found at each port. This creates the impression of a productive, harmonious and benevolent world system of commerce. Audio narration during this first map encounter emphasizes the benefits of globalization and standardization. As participants use their devices to see the major exports of each seaport, they are presented with images of goods that have become indispensible items of daily use in most cultures around the world. When participants decide to choose one item for transport to Malcom, it is a choice that reflects their values as a consumer. For some participants they might have examined each of the 12 locations, heard the facts regarding the use of the commodity depicted at each, and thoughtfully decided what is really important to them and why. Many participants however, simply catered to impulse and chose the first thing that appealed to them.

After depositing their chosen item in Malcom's inbox, participants trigger an additional audio segment in which Malcom directs them back to the map. When they visit the map a second time, the same style of AR graphic overlay appears, but instead of depicting a good export at each port, the AR overlay shows the most common illegal export at each port. These are somewhat disturbing, despite being depicted in the same cheerful cartoon style of the good exports, and include nuclear weapons, narcotics, and human trafficking. Here the map is used to suggest an entirely different narrative – one of discord and violence, and one in which the participant has also played a complicit, albeit unknowing, role. Hopefully, this substitution gives the participant pause and prompts some reflection on the choice they made earlier. Perhaps they question the benefit of a cellular phone when compared to proliferation of arms. Or, perhaps they simply come to realize that there are benefits and drawbacks to a system of this magnitude and complexity.

The act of choosing an item and transporting it to Malcom's desk is, of course, exactly what the container system is designed to do. Through scripting this interaction we effectively ask users to "act like a container" and move cargo from one location to another. Thus, through their embodied interaction they mimic and reinforce a fundamental aspect of the container system. This also serves to heighten their awareness of their own personal involvement in the system, a fact that can become quite uncomfortable when they are asked to transport something harmful during the second part of this interaction. Of course, any feelings of discomfort in performing this action are purely individual, as evidenced by one participant who had his own unique interpretation. After collecting the illegal export, chemical weapons in this case, he immediately left the installation instead of transporting it to Malcom's desk as instructed. He triumphantly returned the device to the facilitators with the phrase "You are carrying chemical weapons," emblazoned on the screen and proclaimed, "I am taking your chemical weapons." We believe this was a playful act, not a purely anti-social one, that nonetheless underscores the consistent theme of personal responsibility and unintended consequences that we wanted to communicate through the installation.

3.2.6 What can we learn about scale from [inbox]?

As I have said, the stations of [inbox] were all unintentionally designed using different spatial scales. The interactions that take place at each of the stations all involve the characteristic embodied interactions of that scale. Although this was pure accident, it supports the notion that scale-thinking is a natural part of the design process when working in MR. However, there are other lessons to be learned, as the stations did not always communicate their message clearly, and I have come to believe that if we had a more conscious understanding of how embodied interactions operate at each scale the project would have been much more successful at communicating meaning than it was.

Much of the analysis above is retrospective. We had only vague notions of what we were trying to express at each of the stations through representation and interaction, and how we were expressing it. If we had had the recognition that we were, in fact, designing for scale than we would have been much more intentioned and reasoned in our application. For example, knowing that the map calls upon the figural scale cognitive processes might have led us to place it on Malcom's desk to further the notion of mastery over the system. We might have split the slides of the slideshow into hanging pictures and placed them all around the room to take advantage of scanning the panoramic space, and support the idea of the ubiquity of the container. We might also have made the act of walking with the containerized object on the device more explicitly about communicating a cognitive map of the containerized world, as cognitive maps are a cognitive structure that relates directly to the environmental scale. While our gut instincts about how to use scale were basically correct, having a framework to guide the connection between our instincts and the scale-thinking of users might have taken us in different directions, provided more insight into what questions to ask during evaluations, sped-up the iterations, and genuinely helped us communicate our messages more effectively. Nonetheless, all was not lost.

Two other important observations regarding scale came from interviews with participants of the experience. The first was that many users were in fact able to pick up on a number of the intentions we had built into each of the stations. I have since come to think about this phenomenon in terms of mental models. As designers we had a very specific mental model that we wanted to communicate to the participant at each station, mastery over the system at Malcom's desk for example. We designed an interaction that we believed effectively communicated that mastery and many participants were able to appreciate something about that mental model when they interacted with Malcom's desk. This process, what I refer to as the sense-making process, is discussed further in the subsequent chapters, and [inbox] presents some compelling evidence that this process is at work in MR design.

A second observation is related to the idea of mental models as well, but is more specifically about scale. One of the major sources of tension in [inbox] was that each of the individual stations conveyed something different about the container system and these did not “add up” to anything for most users. Partially this is because we, as designers, wanted much of the experience to remain open to interpretation, but that decision manifested itself as an experience with very “loose” and tenuous connections between the elements. In terms of mental models, what we were lacking was a consistent mental model that was designed into the experience as a whole and could be accessed by combining mental models from the individual stations. This is also an observation about scale more generally. Essentially, that mental models need to be consciously designed at multiple scales. In terms of spatial scale though, this observation also suggests maintaining some form of *continuity* between scales is essential to creating a meaningful multiscale MR experience. Continuity, in this context is used in a manner similar to how it is used in film and media studies, referring to the idea that elements are connected together both in the formal representational techniques of the medium, and in the minds of users or viewers of that medium. This idea is discussed further in chapter 6, for now I want to return to the discussion on the role of spatial scale as an implicit factor in the design of MR experiences.

3.3 Coordination and Transitioning Across Scales

MR experiences that include multiple scales offer unique and complex opportunities for design. One of the particular opportunities within multiscale design is the ability create connections and relationships between objects at different scales in a meaningful way, maintaining continuity through what I refer to as *scale transitions*. In multiscale experiences, how, when, and why users might switch between representations at different scales is an important consideration. How to make these transitions clear and understandable is a basic concern, but adding additional meaning is an excellent opportunity for creative decision-making. The following case-study discusses one important component of scale transitions, the concept of the *coordination of representations* borrowed from Distributed Cognition, and shows how these concepts can be applied to gain insight into the design of a MR application.

3.4 Return to the Hive: A Case-Study in Scale

The following sections serve as an example of how the MRSF can function as a framework for *re-analysis* of MR experiences. Often, when designing we are only privy to second-hand accounts of existing systems as examples, and this is particularly true for MR where many examples are too difficult to orchestrate repeatedly (Crabtree et al., 2004), or else produce artifacts that require specific times and places to operate correctly. Having a framework, such as the MRSF from which to analyze these second-hand accounts, to compare and contrast, to identify similarities, is potentially quite useful for design as well as research. The following section demonstrates how one might use *scale re-analysis* in conjunction with Distributed Cognition (DCog) to bridge the gap between different systems, and to arrive at new results from previously published material. The idea of *repeatability* as a fundamental element of good scientific research is closely related to this endeavor. However, while that idea is more appropriate for controlled experiments with quantitative results, it is much less appropriate for qualitative work. Here, I demonstrate that a *symmetrical* approach to reanalysis, in which different qualitative results are arrived at from the same data, is more appropriate. The result of this analysis is a qualitatively different explanation of the observed results in which successful "place-making" is understood as a failure of technological transparency. This then allows us to infer a number of design decisions and interactive techniques that could potentially mitigate this failure and create an improved system for the defined task.

3.4.1 Like Bees Around a Hive

"Like Bees Around a Hive," (BeeHive) (Morrison et al., 2009) describes the deployment of an AR enabled physical map in the context of treasure-hunt style game. The original study compares a number of groups using this "MapLens" system, in which augmentations are seen on a paper map through the "lens" of a mobile phone, with other groups using traditional (paper) or digital maps viewed on a handheld device. BeeHive is an excellent candidate for a re-analysis in the context of the MRSF for a number of reasons. First, it is one of a small number of mobile AR deployments outside the laboratory, and therefore emblematic of the unique research challenges facing MR as it moves into the wild. Second, the authors specifically focus on and analyze "embodied interactions" which they define as:

> *"…the use of hands and body to position oneself, and the technology, in the context of other people and the environment."*
>
> (Morrison et al., 2009, p. 1893)

This makes it straightforward to coordinate their data and findings with the MRSF categories as these are also characterized by embodied interactions. Lastly, although MapLens was deployed in the context of game, most of the tasks and activities involved are essentially spatial tasks, such as navigation and way-finding, whose cognitive components and subtasks (path-planning, distance estimation, etc.) are well-studied, even if not yet well-understood. We can see this in the authors' own descriptions of experiences and events. As examples:

> "Most [MapLens] teams used the physical-digital combination for identification of target location, but also for route planning."
>
> (Morrison et al., 2009, p. 1893)

> *"[Digital] teams only needed to stop at places that the tasks themselves dictated, the rest of the action and decisions and way-finding were mainly done on the move."*
>
> (Morrison et al., 2009, p. 1896)

3.4.2 Navigation Deconstructed by Scale

Navigation and its many associated cognitive processes have been widely studied in many research areas from many perspectives. Most notably, for the current discussion, navigation was a core component of Hutchins' original formulation of DCog (Hutchins, 1996). In his description of the "fix-cycle," the distributed cognitive process by which the crew of a large naval ship computes their proper position and heading, he identifies a core concept in DCog analysis, the *coordination of representations* (CoR). The fix-cycle involves creating a number of symbolic representations of the ship's position and orientation across different media, including instruments, logs and charts. These representations are procedurally "coordinated" with each other to transfer the relevant information between media during each iteration of the fix cycle.

The fix-cycle begins with a sailor locating a landmark on the horizon through a telescope. Then, after this information is transposed and reproduced in different forms and media, it is eventually graphed on a map, and the ships position or "fix" is known. What makes this process relevant to our present discussion, and DCog compelling as a theory of cognition, is that the fix-cycle accurately describes a collaborative navigation process that is essentially the same as one done by an individual reading a map (Bluestein and Acredolo, 1979). For an individual attempting to navigate from one location to an unseen destination with only a map of the environment, a similar coordination of representations must occur. They must look around them and find a landmark, essentially an external symbol, create an internal representation of it in their head (remember it) then coordinate that representation with the one found on the bird's eye view of the map. In terms of the MRSF and its underlying model of spatial scales, this process is essentially the coordination of representations from a panoramic space (the immediate surroundings) to the figural space of the map. The goal, of course, is to then plan a path through the environment by doing so first on the map, and subsequently following that path by choosing a heading through the panoramic space. Like the fix-cycle this process can be repeated as often as needed to stay on the appropriate path until the destination is reached.

The first step in analyzing the MapLens study in the context of spatial scale and the MRSF is to classify that system within the framework; this is done by identifying the scales in which physical and virtual objects and spaces mix. Because the MapLens system tracks off of the paper map and adds augmentations in that space, it is considered to have figural scale AR content. There are no augmentations seen when viewing any of the surrounding panoramic spaces, therefore it is not panoramic scale. Also, there is no extension of the mixed reality beyond the map itself, and so, no environmental scale component. However, the fact that all the interactions take place in the context of a game and the navigational activity is framed by this context, suggests that there is a mixing of realities at the global scale. How much, and in what ways, physical and virtual elements are mixed is not well-described in the original BeeHive study; the authors' intent was to focus on the behavioral ramifications of using the MapLens system and not evaluating the game itself. I will therefore continue in the same vein.

The descriptions of the fix-cycle and its counterpart in solo navigation demonstrate, in terms of the MRSF, how navigation can be seen as the coordination of representations across scales. When we analyze the descriptions of user behaviors in the BeeHive study we can see similar coordination of representations across the figural, panoramic, and environmental scales. First, a number of statements demonstrate that the combination of mobile phone and map that comprises the MapLens system functions at the figural scale, which is characterized by manipulation. These statements include observations about users' establishing spaces to use the system:

> "They favored places where they were able to place the map on a table or a bench…"
>
> (Morrison et al., 2009 p. 1894)

as well as whole sections of the original paper devoted to topics such as,

> *"Turning and tilting the objects in hands"*
>
> (Morrison et al., 2009, p. 1894)
>
> *"Use of two hands"*
>
> (Morrison et al., 2009, p. 1894)
>
> *"Stabilizing the map and lens."*
>
> (Morrison et al., 2009, p. 1894)

Clearly MapLens is a figural scale system as our initial classification suggested. However, navigation requires the coordination between the figural scale representation of the environment and the immediately visible panoramic space. The authors offer clues to how their system functions in this task as well. Their comparison of the embodied interactions with MapLens and with a purely digital map on a handheld device reveal that MapLens inhibited the bodily rotation inherent to the "panning and scanning" activities needed to perceive panoramic space. They say:

> *"Turning to gaze [at] the environment was more natural with DigiMap (D) that does not block [the] view and constrain upper body movement as much as MapLens (M)… Consequently, we saw D users more often turning their body or glancing around while using the system."*
>
> (Morrison et al., 2009, p. 1894)

These statements suggest that MapLens inhibits the acquisition of information in panoramic scale spaces, and therefore adds complexity to the task of navigation. Furthermore, difficulties with locomotion, characteristic of environmental spaces, suggest that the system does not function well at that scale either, a point reinforced, by the following statements:

> *"Seven of the eleven teams tried to use M when walking, but all faced difficulties of two kinds."*
>
> (Morrison et al., 2009, p. 1895)
>
> "...the participants' possibility to be aware of their immediate environment was challenged when using M (e.g., a player walked into a lamp-post while looking at MapLens+map)."
>
> (Morrison et al., 2009, p. 1895)

BeeHive also focuses on the social and collaborative aspects of the MapLens system compared to the paper and digital maps, and here too there are some interesting additional interpretations that can be seen when looked at through the lens provided by the MRSF. The main finding of BeeHive, from which the title was derived, is in regard to the "place-making" behavior that emerged from use of MapLens. That behavior, where the users gather around the physical map "Like Bees Around A Hive" is described by the authors:

> *"The physical map as a tangible artifact acts as a meeting point, a place where joint understandings can be more-readily reached and participants were able to see, manipulate, demonstrate and agree upon action."*
>
> (Morrison et al., 2009, p. 1896)

Again we see that manipulation, a hallmark of figural scale spaces, is present in this collaborative use of the system, expectedly. What is slightly less expected, but consistent with the notion of navigation used here, is that the physical map helps the users coordinate understanding, representations, and subsequently actions, as a group in a process the authors refer to as *establishing common ground*. One way to look at this activity, in keeping with the cognitive approach I have been using throughout, is to say that everyone shared a single external representation, and tried to align their own internal representations to make sure that everyone knew what was happening, and they could proceed in unison.

In a work the BeeHive authors cite, Kristoffersen & Jungberg (Kristoffersen, 1999), have a view of place-making that is less optimistic than that found in BeeHive; namely, that it results from a *failure of transparency* in the use of the technology. They state:

> *Our claim is that users should not normally have to be engaged in this kind of activities. They should not have to 'make place' for the device in the mobile situation, but just use it instantly in the situation at hand: it should just 'take place.'*
>
> (Kristoffersen, 1999, p. 279.)

This is not to say that place-making as Morrison et al. describe it is without merit, particularly where social interaction is desired. However, if the explicit task is navigation, as was the goal of the BeeHive experience, and the emphasis is on getting to the destination rather than "the journey" itself, then place-making is counterproductive.

What could the designers of BeeHive have done to make their application a more effective navigation tool? The answer to this question has more implications for the design of a mobile AR system as general navigation aids, the MR campus tour being one of them. From the perspective of the MRSF, the answer is to "augment" the cognitive act of coordinating representations between scales, and reduce the AR features that lead to place-making within the figural space. Essentially, the application should transition smoothly between the figural space of the map and panoramic space of the surrounding world. There are numerous possibilities for doing this, such as adding continuously updated panoramic scale arrows in a heads-up mode to facilitate, or entirely off-load route-planning (this technique can be seen in the GTour app described in Chapter 4), or simply facilitating the manual fix-cycle by providing virtual landmarks that can be matched between scales easily. However, it appears unlikely from the analysis conducted here, and from the original study, that creating a figural scale experience by augmenting a paper map with a mobile AR device is going to aid in navigation without a more explicit augmentation of the cognitive processes involved.

In analyzing and recontextualizing the results from the BeeHive study, particularly user behaviors, in terms of the MRSF we were able to account for the problems the authors observed in the original study and were able to suggest two strategies that should be more effective. This re-analysis serves to demonstrate the ability of the MRSF to provide a unique perspective on the evaluation of MR experiences and supports its usefulness as a theoretical framework for MR. Furthermore, I also identified the concept of the *coordination of representations* as an integral part of successfully designing *scale transitions*. These transitions well become increasingly important concepts on which to focus future design and analysis, and feature prominently in the remainder of this dissertation. The following section describes some general classes of scale transitions, and some very specific techniques for accomplishing these, as well as a number of other useful techniques in multiscale design.

3.5 Designing MR Experiences

In an effort to support the validity of the MRSF as a cognitive framework for MR design I endeavored to determine if the scales of the MRSF were an unconscious factor in the design of these experiences. While I have already shown that it is possible, through artifact analysis and reflection on the design process, to see evidence of scale-based thinking in MR applications, I wanted to focus more directly on the thinking of MR designers during the design process to see if and how scale played into their decision-making. To that end I interviewed three local MR designers, all of whom began working with the Augmented Environments Lab at Georgia Tech (AEL) in a graduate level seminar, and who continued to do advanced MR projects as independent coursework. All of these exhibited some evidence of thinking about scale at different stages of their design process. I had each subject arrive for an hour-long interview with some demonstrations of the MR projects they designed to act as prompts for the rest of the semi-structured interview. After asking basic questions about their technical background, interests in MR, and general design approach, I had each subject walk me through each of their applications while I asked them questions intended to stimulate them to reflect on their design choices, goals, and the outcome of their designs. What follows is a discussion and analysis of each subject's interview data.

3.5.1 Subject #1

Subject #1, despite designing multiple MR experiences, showed very little ability to reflect on or articulate design decisions, and so was the least informative. The main reason for this seemed to be that this individual felt very little ownership over many of the projects he worked on. Although he was ultimately responsible for implementing these designs, he often found that he was the only member of the group with the technical abilities needed to do so, and therefore defaulted to the role of "programmer," rather than being more intimately involved in the decision-making. Nevertheless, in the instances where subject #1 reported offering design suggestions, there was substantial evidence of scale-based thinking.

When reporting on the design of a museum guide application, this subject mentioned that he suggested the idea of being able to take the tour in different "personas." His example of this was a "snobby art guy," which he further explained was someone who knew many intimate details about individual artworks and artists, and was not shy about showing off this knowledge or letting patrons know his opinions about individual works of art. Although his design team rejected this idea because, he claims, they felt it would be too difficult to create the different personas, it nonetheless demonstrates a compelling approach to the global framing of a museum experience. Where a typical curator on a museum tour often aims to be as objective as possible, telling only facts and occasionally relaying a compelling story or interjecting a personal opinion, this fictional MR "art snob" would turn this approach on its head by constantly offering opinions, potentially omitting important information that he didn't want you to hear, or otherwise "coloring" the experience. This is exactly what global framing accomplishes, and I personally find the idea of an "unreliable narrator" for a museum experience is an interesting approach to framing an MR experience.

A second example of the role of scale in subject #1's design approach came when he described the way he thought about how to implement an application to aid users in the assembly of furniture. This application was intended to be used at the figural scale, with the user pointing a handheld device at a page of instructions and figures, and seeing animations that showed each step in the assembly process. Subject #1 described his initial conceptualizing of this idea by using an analogy:

> *"Route directions are hard for me, I'd rather someone just pointed and said, 'its right there. Do you see the building there? that's the one.' I tried to take that approach into AR. I applied that to instruction manuals for objects."*

Although it is not explicitly clear what it is about directional pointing that subject #1 wanted to transfer to his instruction manual application, this statement demonstrates the use of analogical mapping of a relationship from the panoramic scale to the figural scale. Firstly, subject #1 is describing his frustration with "route directions" which presumably has something to do with his inability to remember the complexities and uncertainties that often accompany such directions. Recognizing landmarks, the order of instructions, the details (left vs. right turns), etc. are difficult for many people, subject #1 is not unique in that regard. Route directions are environmental scale constructs, they are a stepwise method of locomoting through environmental space. Subject #1 suggests an alternative to complex environmental scale navigation, namely a panoramic scale approach. He says he prefers that someone just point to the location, essentially locate the destination in panoramic scale space, and let him find his own route there. Of course this is only possible if the destination, or an important landmark is currently within the bounds of the panoramic space, and the subject agreed that indeed is a limitation of his scenario. Nevertheless, he remained steadfast in his assertion that this approach was a good analogy for his furniture assembly application. He argued that this seems to be exactly the approach that many assembly manuals follow. They show a picture of the finished step, or a diagram of the components and connections, so that the user can simply work to achieve that goal on their own rather than follow the complex and often vague steps outlined in language.

From this point of view, it appears that what subject #1 actually objects to is the use of language over images, and this is what he hoped to stress in his design. While this makes his motivation no longer specifically about scale, there are scale elements here that should not be ignored. The use of navigation as an example is an interesting choice and the simplification of stepwise locomotion into a visual search is a useful one. Unfortunately, subject #1 never finished his implementation, so we cannot see whether the final result actually achieved his goals, or know exactly what features of panoramic directional pointing he was able to transfer to the figural scale. Nevertheless, the fact that his statement showed a clear conceptualization of a reduction in scale and the desire to transfer this relationship to his application, at the figural scale, is clear evidence of scale based reasoning and analogical transfer at work in his design process.

3.5.2 Subject #2

The second interview subject was the lead designer on a number of iterations of a major MR museum guide. The subject was an expert on the Georgia folk artist, Howard Finster, and wanted to create a MR application that would introduce museum-goers to his artwork. The High Museum in Atlanta has a small room dedicated to this artist's work, and own's many pieces, however, Finster was a very prolific artist, and chose to display his art at his own home, Paradise Garden. Much of this artwork was built in-place, meaning that it was part of the actual structure of Paradise Garden itself, and created specifically to be exhibited in that space. After Finster's death, Paradise Garden fell into disrepair, and the artwork was removed from this context and sold piecemeal. Although some of it did find a second home at the High Museum, subject #2 did not believe this was adequate. He believed that Finster's work needed to be seen in its original context to be appreciated and he believed that MR could help to accomplish this.

While subject #1 discussed mainly his technical achievements with using MR, the various features he added to experiences that brought the design team's vision closer to reality, subject #2 expressed mainly technological frustration. His goal for his MR experience was to recreate the environment of paradise garden using a combination of tangible objects, and virtual scenery. Because the physical artifacts, Finster's artworks, were on display in a museum setting, the surrounding artifacts were all stationary and, at least theoretically, possible to track using computer vision. Subject #2 wanted to take advantage of this situation to create a virtual approximation of Paradise Garden. However, he quickly realized that this goal was out of his reach due to technical, time, and personal constraints. Nevertheless, the fact that his first inclination was to map one environment onto another and maintain the scale of the experience is a telling one, because it is so natural. If the goal was to create a feeling of Paradise Garden as a place, the most intuitive way to do so would be to recreate that environment as closely as possible, to match the scale of the experience. Although Subject #2 was not able to accomplish his goal of recreating paradise garden as an environment in MR, he was able to accomplish what he believed was the next best thing. Using a series of panoramic spaces featuring Finster's artworks, he was able to achieve an approximation of the actual environment. This idea, that we can summarize as *environmental approximation* is a natural one, but, as the discussion below will show, quite a powerful and common one as well.

3.5.3 Subject #3

Subject #3 was by far the most experienced and technically sophisticated MR designer that I interviewed, and this sophistication showed not only in the rich collection of experiences he created, but also in his intuitive and sometimes clever use of spatial scale. Subject #3 estimated that he had completed 8 MR applications using the AEL's Argon Browser. These ranged from mono-scale utilities to more full-featured multiscale applications. The first, and one of the more interesting in terms of scale is an application designed to help users locate their desired bus route. As shown in figure 3.5, after the application is loaded the user points their device at a map of local bus routes. At this point the application treats the map like a fiducial marker, and augments the map with live data from a bus positioning service. This is a figural scale interaction, and essentially works just like an interactive map would, it projects environmental scale information, bus routes and locations, into a figural space.

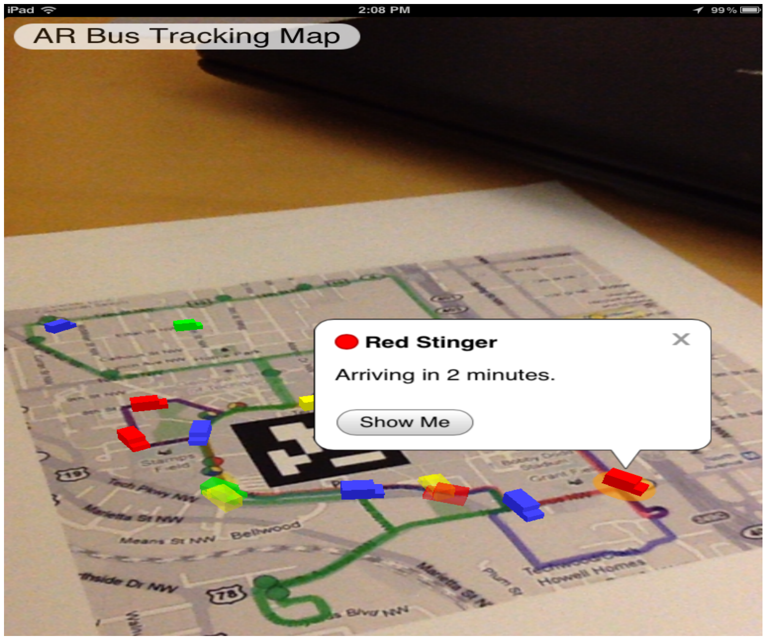

Figure 3.5. Interactive Bus Tracking on a paper map.

The more interesting part of the application however has to do with how users locate their own position relative to the bus routes. While a typical navigation application uses a unique identifier to represent the user's current position on the map, this application relies on a scale transition. Rather than showing the user's current position and letting them plan their own route, this application uses a "heads-up" arrow to point the user in the direction of the nearest bus stop for their desired route. Clicking the "show me" button in the pop-up balloon calls up a 3D arrow in the vista that the user can use to navigate through the environment. This can be seen in figure 3.6.

Figure 3.6. Arrow indicating direction of desired bus route.

A second application developed by subject #3 uses scale very differently, and can be thought of as a kind of walking tour as well. This application was created as a MR "transmedia" experience using content from the Walking Dead television series. When the application is loaded, the user sees the opening image from the television series, and if the user selects that image by clicking it, a panorama fades into view showing the real-world location with the image from the show inserted into the scene from the correct vantage point. This is shown in figure 3.7. While doing this kind of blending seems natural given that both MR and film arguably seek to emulate the way humans naturally experience space, it is also an example of scale-thinking at work. The image itself is only a vista removed from its panoramic context, the goal of the designer in this case was to reassemble the panoramic space by reinserting the vista. In doing so, however, the panoramic space isn't simply recreated, it is remixed to create a blended reality. This sentiment is echoed in the designer's own statements:

> *My goals were to explore…I guess…blending multiple realities together…trying to merge the fictional with the real world to give people a feeling of presence even if they are not able to be [in] downtown Atlanta and see this real world place.*

While the experience of watching the television show and the experience of using this application remotely, as subject #3 describes, are both technologically mediated experiences, subject #3 believes that remixing them in the manner described above can potentially create a greater feeling of presence. Interestingly, this is very similar to what subject #2 was attempting to do by recontextualizing Finster's artwork into a panoramic space. The similarity of these designs suggests that there is an intuitive idea that panoramic space feels more "present" than a simple vista space. This is potentially attributable to the "panning and scanning" interaction that takes place at the panoramic scale, a point that further demonstrates the power of embodied interaction to effect a different cognitive state.

Figure 3.7. Blended image from the Walking Dead inserted into panorama.

The second feature of the application also shows some very clear scale-thinking. When the user clicks the arrow shown in the left of figure 3.7, a new panorama loads featuring a different location with similar blended content, as shown in figure 3.8. I refer to this technique as *panoramic sliding*, moving effortlessly and smoothly between one panoramic space and another.

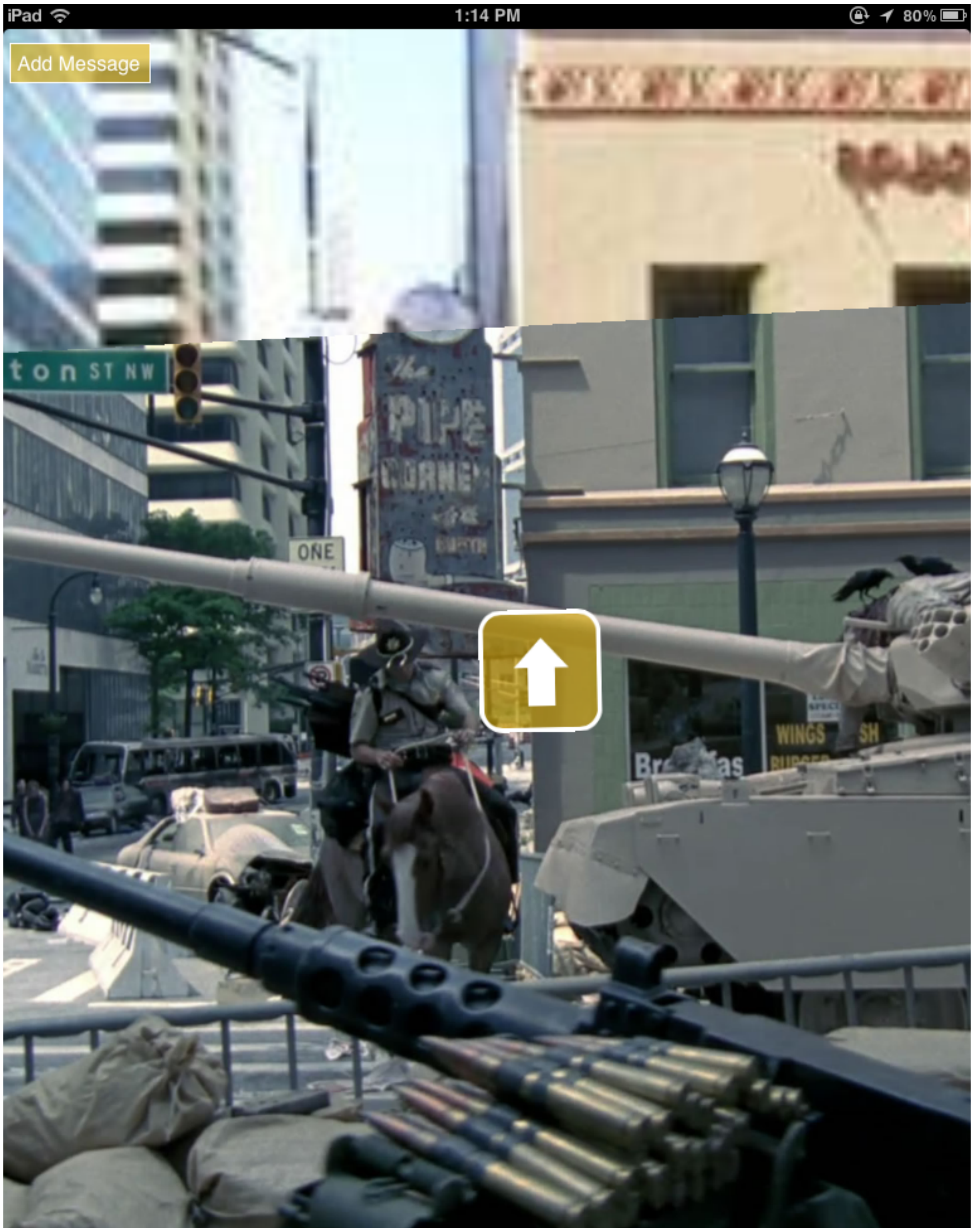

Figure 3.8. Additional panoramic location from Walking Dead companion application.

This collection of panoramas, linked together through icons, creates what subject #3 refers to as a "grid," and together he believes the collection sums up to an environmental space that consists of much of downtown Atlanta. Again, we see the concept of *environmental approximation* at work. Subject #3 describes this by saying:

> *The goal is to add similar content to these areas that would allow the user to explore both the world of the Walking Dead and downtown Atlanta at the same time.*

What I find most interesting here is that there seems to be an implicit distinction being made between the environment of “downtown Atlanta” and the “world of the Walking Dead.” Of course the spaces are the same, content is simply blended into a mixed reality as described above, but to subject #3 the Walking Dead is an entire “world” and downtown Atlanta is only a part of it. The word “world” of course is synonymous with the word “global,” and it appears that while the environment for this experience is downtown Atlanta, it is the Walking Dead that frames the experience of that space at the global scale. To a user of this MR application, downtown Atlanta can become a different place, a singular environment nested inside a totally different world.

The experience created by the Walking Dead Television Companion application doesn’t stop there. Because scenes from the television show were photographed all over the Atlanta metropolitan area, there are numerous other locations to explore, all with similar panoramic content. However, unlike the panorama grid of connected locations accessed by selecting on-screen arrows, these locations are accessed via a map screen as shown in figures 3.8 and 3.9. This map identifies each location of active panoramic content with an icon image representing the entire panoramic space. Clicking one of these icons calls up a content balloon with an additional picture and some details about the location. Clicking again loads a full panorama like the ones described above. The interesting thing about these panoramas is that a user can only access them through the map itself, and not through the clickable arrows. The user must enter the map space in order to move between panoramas rather then “sliding” or “jumping” between them, as in the previous example.

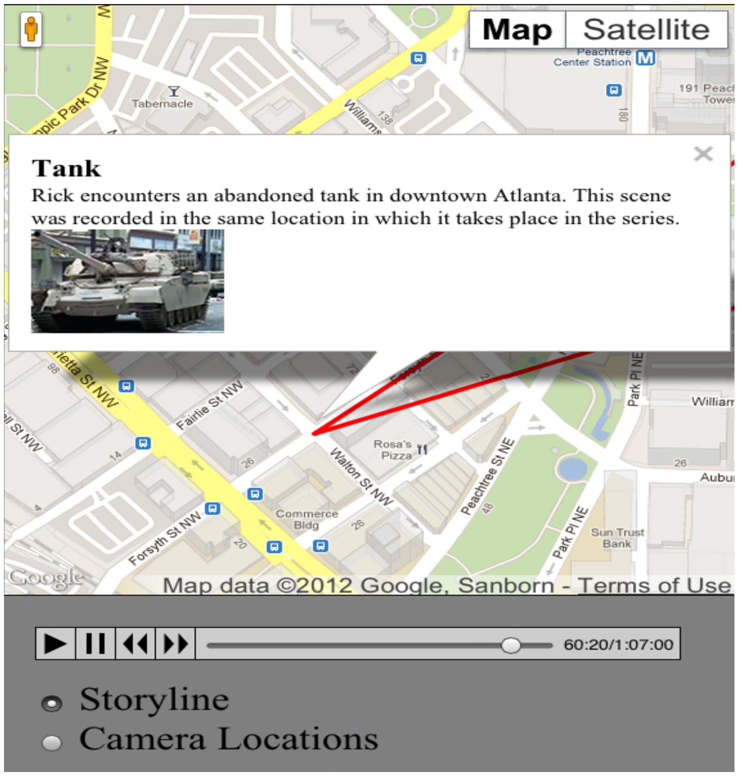

Figure 3.9. Initial location of panorama grid seen from map screen.

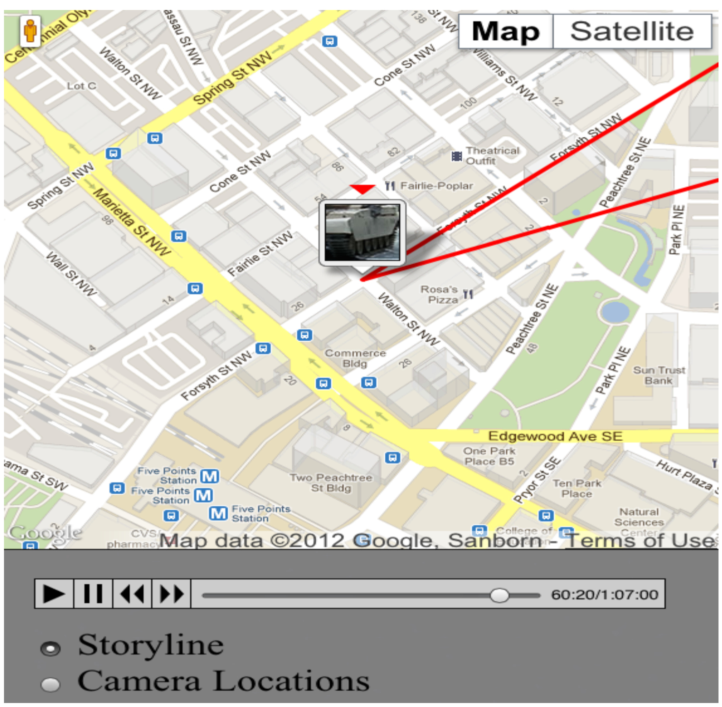

Figure 3.10. Icon mode of downtown Atlanta location with route lines connecting it to additional panoramas in other parts of the city.

There is no technical reason to limit access to these panoramas to the map screen, as they could just as easily have been arranged in a grid with identical functionality to what was described above. When I asked subject #3 why he constrained this part of the application this way he responded with a clear indication of scale thinking:

> *The spatial separation between the content items sometimes ranges in the hundreds of miles. So, I think in designing the panorama grid of downtown Atlanta where the distance was less than a block between panoramas there's that feeling of immediacy and visual connection between one panoramic geospot and the next, you can actually see where you'd be heading…when the separations are between cities, potentially, I felt like the visualization of a map affords a greater comprehension and immediate understanding of the relationship between these two locations…They can see the disconnect between those two places. If it were just a series of clicking through arrows pointing you in the right direction in might be more jarring or less clear when you've left one environment and moved to another.*

There is much to analyze here. First, the notion of a "visual connection" between panoramic locations is clearly related to the boundaries of the panoramic space. The MRSF claims that the boundary of a panoramic space is based on "line-of-sight," and this seems to have been intuitively grasped by subject #3, who made design decisions based on his feeling that the user's ability to reconstruct an environment through mentally integrating panoramic spaces requires the ability to physically see how those panoramas are related to each other. What's more, the subject's claim that visual connection helps to create a feeling of immediacy that is greater than one in which panoramic spaces are separated by larger distances helps to connect the MRSF to notions of "presence." We might infer from this an inverse relationship between scale and presence, with smaller scales being associated with greater presence. Also, subject #3 seems to be embracing a notion of "place" at the environmental scale. He does not appear to distinguish panoramic spaces as different places, but rather appears to conceive of a collection of visually connected panoramas denoting a single place. His final statement reinforces this view. When he says that clicking an arrow to move to a panorama that is visually separated from the others makes the physical separation less clear, he is speaking entirely about perception on the environmental scale. It is certainly still clear that the user is transitioning between panoramas, but the implication is that these are visually connected, and therefore part of the same environment. However, having to transition between panoramic spaces using the map implies that the panoramas are discontinuous.

Another indication of global scale framing can also be seen in figures 3.8 and 3.9. The radio buttons at the bottom of the interface labeled “camera locations” and “storyline” represent two different ways of organizing spatial information in the experience. Although the majority of the locations used as sets in the filming of the Walking Dead series are located in and around Atlanta, the action of the story is set in numerous other locations around the South and Midwest of the United States. The user of the application has the ability, through the use of the radio buttons, to decide whether they want to view panoramas in the context where they were actually filmed in the physical world, or in the context of the virtual world of the story. They are given a choice in how they want to frame their experience at the global scale, and can potentially even jump between framings if they want to receive information about the storyline or about the production of the show.

There is one last scale element involved in this application. Where subject #3’s bus locating application implemented a scale transition from the figural space of the map to the vista directing the user to the bus stop, the Walking Dead application implements the opposite transition. When the user places the device horizontally, on the surface of a table for example, the map automatically slides into view. From a scale perspective, when performing this action, the user is no longer viewing the world through the device, it is no longer a window, and therefore they are essentially transitioning from the panoramic space to a figural space. This makes the use of the map much easier, as it is a figural scale object, and the user can now touch, pinch, click and drag the map around. Using this embodied gesture as a kind of *embodied trigger* to change the state, and scale, of the application makes for much more fluid interaction.

3.6 Summary

I began this chapter with a discussion of spatial scale as an unconscious influence on the design of [inbox], and explained that a more intentioned application of scale might have resulted in a very different experience that might have helped participants make more meaningful connections to the subject matter. I noted that one major failing of the [inbox] project was a lack of *continuity* between the different stations that comprise that experience. Stations communicated isolated meanings that were not integrated into a larger whole. One interpretation of this lack of continuity, understood in terms of mental models, was that mental models communicated at the individual stations did help build an aggregate mental model of the complete experience. Although this observation is best interpreted in the context of a more general understanding of scale where interpretations of lower-scale stations summate to a larger-scale meaning of the entire experience, it is also an observation applicable to the specific case of spatial scale. We might ask the question of how we can achieve greater continuity between interactions at different scales.

One answer to that question was found by using spatial scale as a sensitizing concept for re-analysis of the BeeHive study. By using scale as a mediator we were able to compare navigation as outlined by Hutchins with the authors' account of navigation in the BeeHive study. The resulting concept of *coordination of representations* allowed us to show that the place-making behavior described by the authors could be directly attributable to failure of navigation brought about by a lack of coordination between representations in the implementation of the MapLens system. I then suggested approaches to augmenting coordination using the system by implementing a heads-up display for navigation, or providing explicit virtual landmarks common to both the map and the surrounding environment as two possible solutions in this vein.

In a further effort to show the influence of spatial scale on the design of MR systems and to identify particular techniques for coordinating representations using *scale* *transitions* I discussed interviews with three MR designers. These demonstrated that spatial scale was a factor in their thinking in a multitude of ways. First, Subject #1 made analogies across scales to inspire his designs. Second, Subject #2 intuitively adopted the technique of *environmental approximation* in which a collection of panoramic spaces is used to approximate a more complex and immersive environment, a technique also used extensively by Subject #3. That final subject also implemented a number of other techniques as well. These included an example of *embodied triggers,* such as animating a map into view when the user pointed the device downward. Subject #3 also intuitively implemented a heads-up display hypothesized as a solution to the navigation problem in the BeeHive study. Other techniques mined from an analysis of these experiences included *panoramic sliding* as a means of moving between one panoramic space and another, as well as extensive use of global framing such as separating the panoramic clusters by requiring the user return to map to access new environments.

CHAPTER 4

THE CAMPUS TOUR

4.1 The Analog Campus Tour

4.1.1 Beginning the Tour Through the World Wide Web

During the course of this research I have participated in, and observed, six different campus tours and information sessions. These tours are a representative sample of the tours any given prospective student or other visitor would take. They all have a similar structure, but the content, although constrained by the provisions set forth in the "Campus Tour Manual," varies based on a number of factors. The Georgia Tech Office of Admissions, which coordinates the campus tours, compiles the manual, and trains the tour leaders, maintains a website[1] that is intended as a portal for prospective students to begin their relationship with Georgia Tech. This webpage is instructive on a number of fronts.

[1] http://www.admission.gatech.edu/visit

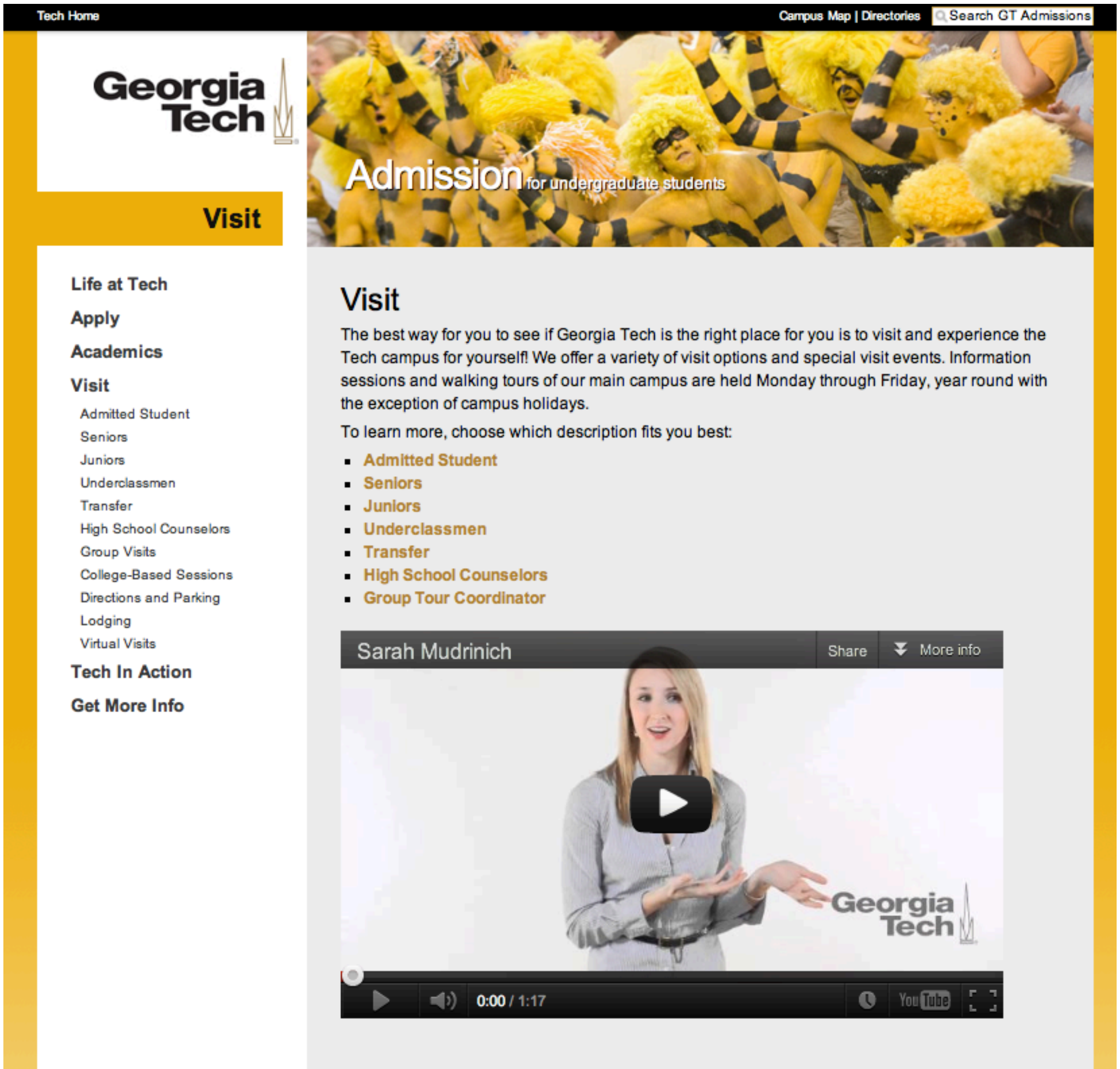

Figure 4.1 Campus visit web portal

Moving further down the page, one encounters seven categories that can be selected to funnel the visitor to a webpage that is intended to more closely match their needs. The seven different categories operate to frame the participants' introduction at the global scale. Each category appears to tailor the information delivered to the particular class of visitor. For example, the page that is linked from the "Juniors" category displays the text:

> Your junior year is an important time to start narrowing down your college choices. Students report that visiting a college is the best way to determine if it is truly the right fit. Georgia Tech wants you to see our campus for yourself. Our

> programs offer you the opportunity to learn more about our academics, our campus life, and what it is like to be a Yellow Jacket!
>
> (http://www.admission.gatech.edu/visit/juniors)

This statement is intended to appeal to the experience of a high-school junior that is perceived to be common throughout local, regional, and national high-school cultures, thus it has appeal at the global scale. The statement also attempts to entice students to be physically present on campus.

Other categories are framed similarly and geared toward the perceived needs of the different communities they target. As one might expect, certain options are only available for certain categories. For example, overnight stays on campus, called the "Connect with Tech" program are only available to admitted students. Other programs are geared toward different sub-sets of prospective students, such as female, African-American, or Hispanic students. However, two options are present across these categories. "Preview Georgia Tech" and "Daily Visits" both feature the campus tour and information sessions I participated in.

Information sessions, which are hour-long presentations, mirror this same structure of tailored content for different classes of attendees. There are individual sessions for admitted, transfer, and prospective students, and these can also be understood as serving the purpose of framing the experience at the global scale. More importantly though, as I discuss below, these sessions also serve as a kind of group scale-transition, in which ideas from the global framing of the experience are directly linked to aspects of Georgia Tech's culture, aspects of the environment which will be introduced on the walking tour. This use of alternate framings is accomplished much more subtly in the MR version of the campus tour described below, but the need to transition remains and is an important aspect of the analog campus visit that we wanted to preserve in the MR version that we might not have been aware of, or at least been able to articulate, without a sensitivity to scale in our design process.

4.1.2 Information Sessions as a Scale Transition

The actual campus tour is a multiscale experience. As described above, the information sessions that begin each tour offer additional global scale framing. These sessions address issues of Georgia Tech's relationship to the wider world, such as internship and job opportunities, study abroad opportunities, and a geographic and cultural summary of Atlanta. Additionally, these sessions also deliver information about Georgia Tech at the environmental scale as well. Visitors are introduced to a litany of campus organizations, demographics of the student body, and the different colleges and schools that comprise the institute, complete with pictures and data.

This information can be understood as an attempt to transition between global and environmental spaces. Different aspects of global scale framing are emphasized in the different information sessions, in what I would describe as an attempt to preserve *continuity* as the visitor begins to transition into the environmental space encountered on the walking tour. The final step in this group scale-transition is an actual physical transition in which participants leave the auditorium and step outside to begin their walking tour.

4.1.3 The Campus Tour

The tour itself is comprised of both panoramic and environmental spaces. It begins with a tour group gathering just outside the building to be introduced to their tour guide. The group then walks at a sometimes painfully slow pace around campus. During this time the tour guide tells stories about campus life and notable alumni, reveals bits of history about the campus, and gestures to call attention to important artifacts. This aspect of the experience occurs at the environmental scale and the information it contains is general information about Georgia Tech. This brings up the important concept that the scale of the information delivered matches the scale of the mode of experience, what I refer to as *scale-matching*.

However, the tour is not a continuous walk through the environment. Instead there are a number of “stop-and-talk” points; points at which the tour stops as a group and the tour guide directs attention to various aspects of the immediate panoramic space. These panorama points are integral to the tour for a number of reasons. For one, they allow the guide to go into considerably more depth because the scenery is not changing as quickly, even more practically, they allow slower participants to catch up to the group. They also allow the group to transition into different spaces, such as classrooms. These panorama points are a natural correlation to the virtual panoramas used in many MR applications and feature heavily in the MR tour.

The actual content of the tour varies from guide to guide and from tour to tour, making each tour a unique experience, however they all contain the same basic elements of history, student life, academic information, and trivia. While individual tours reflect differences in individual guides, figural scale elements remain constant. Figural scale elements consist of flyers and pamphlets that the visitors chose before or after the information session and carry with them during the tour experience. I observed a number of visitors examining these during the tour, while others simply packed them away for later use. Those who did examine these materials did so predominantly during periods of walking, and at the expense of paying attention to the tour guides. Participants often had difficulty focusing on both the written materials and the tour guide. This was evidenced by the fact that participants who attempted to do so often looked up from the materials and asked a companion a question; typically something along the lines of “What did he say?” or “Where are we (going)?” or “What’s this place again?” Interestingly, participants often stopped reading the written materials when the tour reached a stop-and-talk point. Presumably, this is because stopping suggested that information relevant to the immediately surrounding area was about to be offered. This can also be interpreted in terms of a scale transition. Where the environmental scale information delivered while walking is less concrete, more general and conceptual, the information delivered at panoramic stop-and-talk points is typically directly tied to the space. Again we see that *scale matching* between information and space is a key concept here, and the behavior of the participants suggests that this is their expectation. In addition to the finding that scale matching as a general design principle for the MR tour, this analysis also suggests that better coordination of representations between the panoramic scales and the figural scales is another potential benefit of technologically enabled MR campus tour.

4.2 Design of the Campus Tour and Associated Systems

There are many choices to be made in the creation of a Mixed Reality campus tour; however, at some level the basic structure of any tour will have many elements in common. The previous analysis focused on the basic structure of the analog tour experience, identifying some important aspects of the analog tour that we wish to preserve, some opportunities for improvement, and formulating the over-all strategy of communicating mental and cultural models as multiple scales. It is now time to put those observations, and the MRSF framework, to use. The following sections describe the implementation of the MR campus tour and its supporting systems. This system is the result of three design iterations, at times involving some substantial refinement as well as minor adjustments, and I discuss the reasoning behind the choices and trade-offs that were made in regard to the final, end-user tour and the tools that were developed along to support its maintenance and further refinement. Insights gained from the analysis of the analog tour and re-imagined and embodied in the MR versions, and the essential concepts of multiscale design, such as scale transitions and scale matching are used to understand and solve problems that occurred throughout the design process.

4.3 Tour Overview

The Georgia Tech Mixed Reality Campus Tour, GTour for short, consists of an end-user self-facilitated MR tour experience available on an iPad2 or later generation iPad, as well as a suite of web-based tools for curating content, and a “Positioning Tool” also designed to be used on an iPad that allows for visualization and three-dimensional positioning of tour content. To help ground a discussion of the implementation details, it is best to give a brief overview of the end-user tour itself, and how it embodies the principles found in the MRSF. The tour is delivered using the Argon AR Browser[2] developed in the Augmented Environments Lab (AEL) at Georgia Tech. Argon can run on any iOS device, but the tour was made specifically for the iPad, to take advantage of the larger screen space.

The "Home" screen (Figure 4.2) introduces the user to the tour:

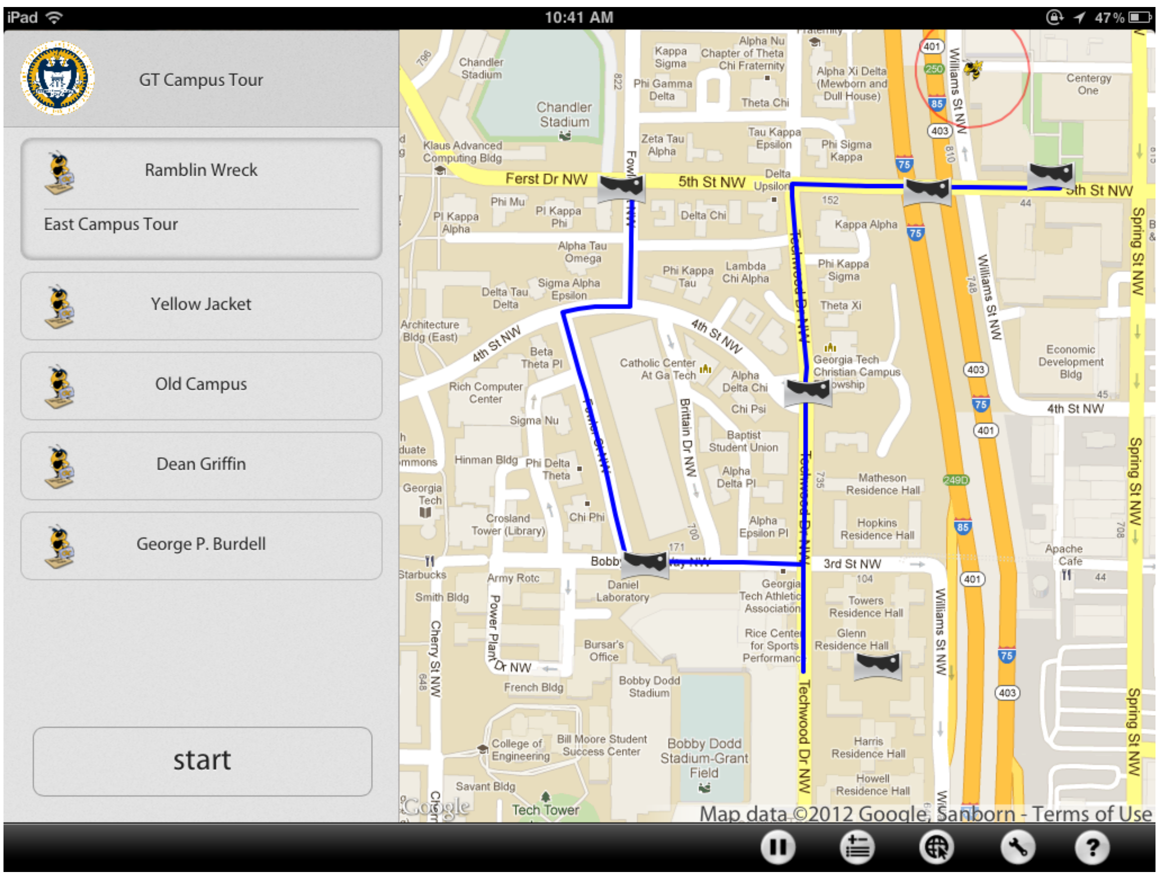

Figure 4.2. Home screen for final iteration of GTour application.

The left side of the screen consists of an "info pane," that serves as a canvas for media elements throughout the tour, here it provides a means of selecting between the five designed tour routes. The main portion of the screen is occupied by a map of the campus,

[2] Argon website: http://argon.gatech.edu/

and contains useful navigation information. This screen serves a number of purposes from both a usability standpoint and in terms of scale. In terms of usability the screen introduces users to a number of important interface elements: the info pane, which holds content in all modes of the app, and the map screen with location icons, tour route, and current location. In terms of scale, this screen has elements at every level of scale, projected into the figural space of the screen, it is a map in every sense of the word. There are figural scale control elements, such as buttons in the info pane, and touchable (clickable) icons on the map. The campus map is a figural scale representation of the environmental space, and the clickable icons represent the individual panoramas that are the main interfaces for content in the tour experience. The map also contains a "trajectory" through the panoramic spaces, the tour route, represented by the blue line, and an icon of Buzz, Georgia Tech's mascot surrounding by a flashing red circle that denotes the user's current position.

On the Home screen the info pane lists five possible tours that the user can take (although more are possible), and clicking on one of these buttons brings up a short description of the tour and loads the appropriate map. Two further examples are shown in Figures 4.3 and 4.4.

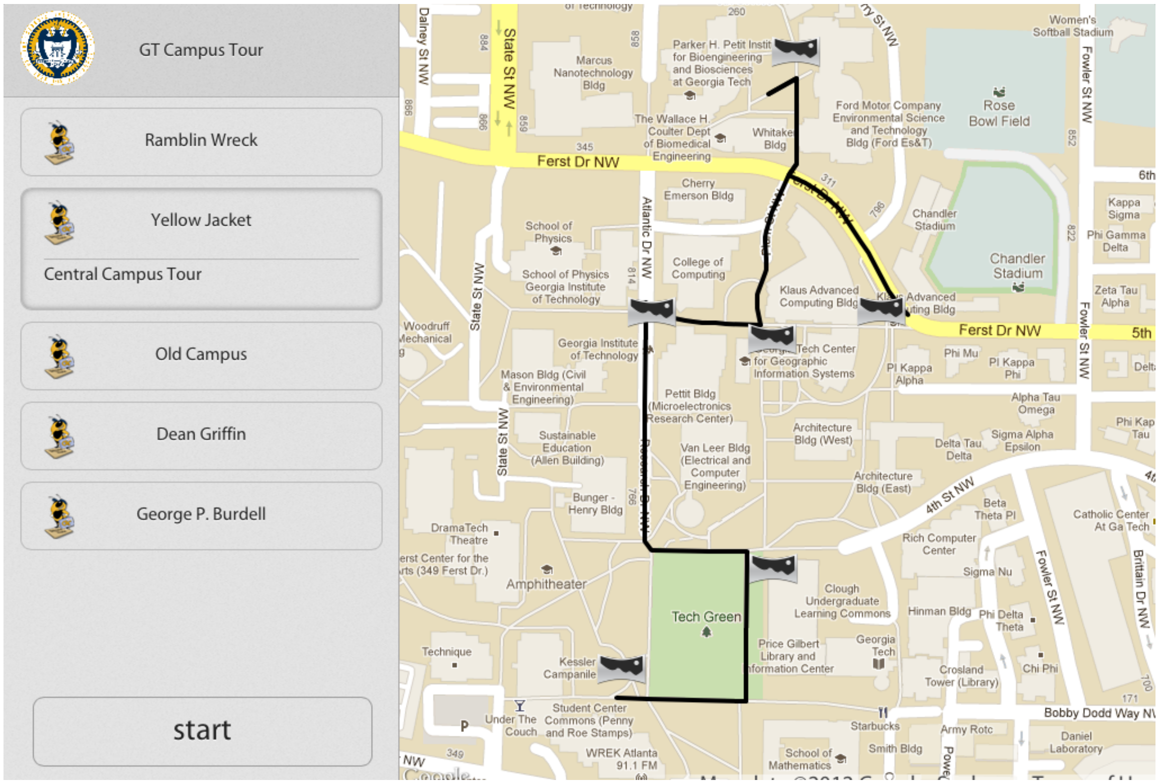

Figure 4.3 Yellow Jacket tour route from GTour application

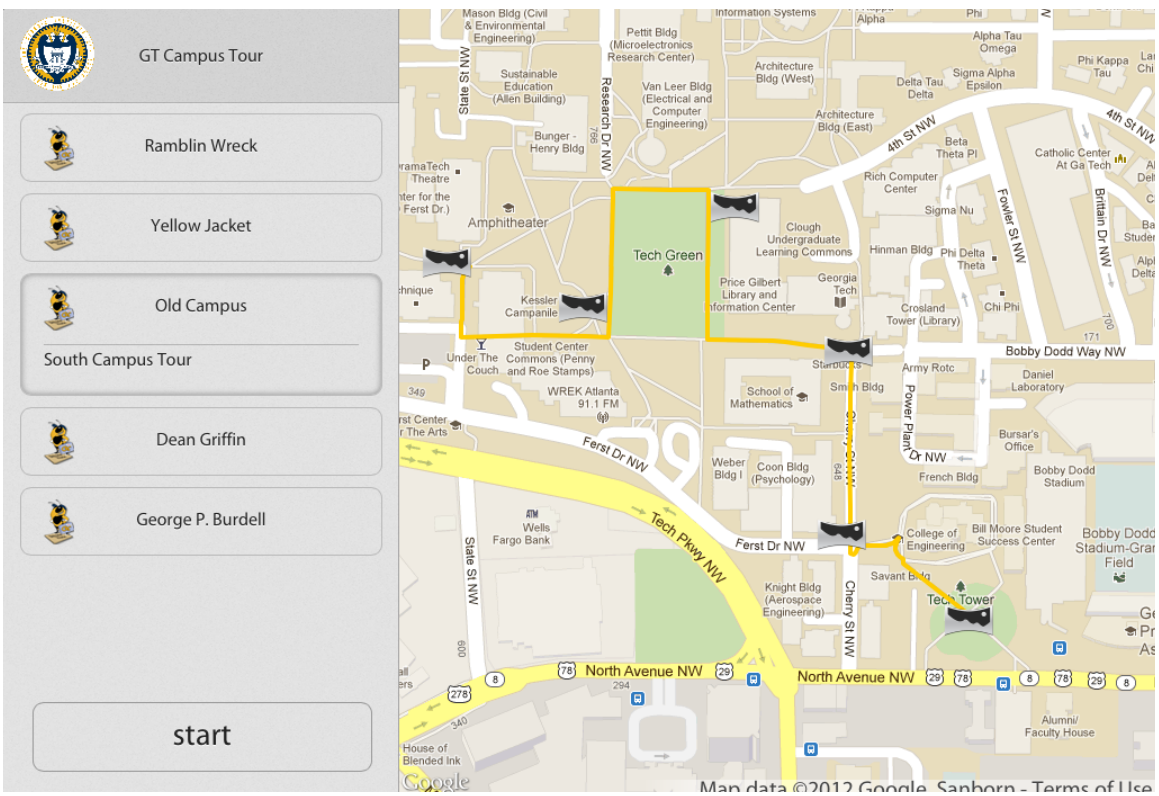

Figure 4.4. Old campus tour route from GTour application.

The ability to select different tour types is a global scale element, which serves to frame the tour experience. This framing also trickles down to the other scales as well, changing the tour route, the panorama points it contains, and the parts of the environment that a participant is introduced to, as well as the order in which they are experienced. Furthermore, selecting one type of tour or another is reflected in the content delivered in each individual panorama. I will explain this idea in more detail below, the important point to note here is that the Home screen contains representations at every spatial scale.

Because the tour is a multiscale experience, having all the elements represented on the Home screen is conceptually and practically useful. As an introduction, it orients the user to the different scales of information available so that they become familiar with the different ways information is being presented. If the user is ever "lost" during the tour, either physically or conceptually, a quick press of the Home button, brings them back to this screen where their relationship to all the other scale elements is presented and they can re-orient themselves if necessary. They can see their location in the environment, return to any of the panoramas, and even change their selected route to re-frame the experience if they wish.

After selecting a tour type, touching the start button in the info pane begins the tour by directing the user to the starting panorama, or nearest panorama if the route is a loop, and automatically loading that panorama when they are within a fixed distance determined by the error in gps positioning accuracy. Directing the user from panorama to panorama is done with the application in "camera" mode, using a 3-dimensional arrow that points the user toward the next panoramic "tour stop." Text above the arrow displays the name of the next tour stop as well as the distance in meters.

Figure 4.5. 3-dimensional arrow directing user to next panorama

The yellow arrow is anchored in the vista, and provides the user with a representation that helps guide their orientation in the environmental space. In Chapter 3 I discussed the lack of a vista representation as a potential cause for the "place-making" observed in the BeeHive study, and suggested that a "heads-up" display could effectively offload some of the cognitive work of coordinating representations between the vista and figural scales. The implementation of this floating arrow is an attempt to do just that. The tour user does not need to return to the map screen to determine how to navigate to the next location. If they wanted to they could, simply by pressing the "Home" icon on the screen, but they can also simply follow the arrow to the next panorama point. In addition to offloading the need to coordinate representations between the figural and panoramic scales, this mode was also built to preserve a useful feature of the analog tour. During the frequent walks between panorama stops the tour guide delivers information about the general environment of Georgia Tech. Although not implemented in this version of the tour due to constraints on available content, following this arrow provides the space for designers to include an audio (and perhaps even video) track that fills the roll of the tour guide. Information relevant to the theme of the tour, particularly information about areas not included in the limited tour route, can be included to present environmental information. Here GTour creates a virtual space at the environmental scale that tour designers can fill with whatever content they want without damaging the integrity of the tour.

Upon arriving at a given location the panoramic tour stop associated with that location is loaded automatically, giving the user an augmented reality view of the space. These panoramic tour stops are really the heart of the application where most of the content is delivered. An example is shown below in Figure 4.6.

Figure 4.6. Section of panorama associated with the Kessler Campanile.

Each stop consists of a number of "placemarks" that call out objects in the surrounding space as having additional information. Although the GTour application gives these placemarks a clean and uniform look-and-feel as shown in 4.6, they are simply containers for html content, and can take on any shape, or hold any formatting possible in html. This allows the global framing of the experience to "trickle-down" into other aspects of design. Copying the look of a periodic table of the elements for chemistry majors, is an example of how this might be accomplished. In that light, this is yet another opportunity for designers to potentially more closely match specific tours with particular interests of tour participants' and give them a more personally meaningful tour experience, an aspect of the analog tour that is currently missing.

When a user selects a placemark by touching it on the device, the info pane is populated with additional content specific to that placemark, as shown in Figure 4.7.

Figure 4.7. Additional content associated with Kessler Campanile placemark.

This mode presents an interesting connection between vista and figural spaces. For one, although the space of the screen is inherently a figural one, the fact that it functions as a window onto a representation of the immediate surroundings closely associates figural interactions with panoramic ones. This is particularly true when the info pane is closed (as in Figure 4.6). The act of selecting a placemark to access additional content, combines the figural scale interaction of pushing a button with the panoramic scale interaction of pointing to an object in view. Directional pointing has been shown to be a panoramic scale activity (Hegarty et al., 2006) and this suggests that the device is functioning more at the panoramic scale than on the figural scale in this particular mode. However, the use of this same interactive gesture, a form of *embodied trigger*, at both the figural and panoramic scales also works to coordinate the two scales together and serves as a natural place for a scale transition. Once the placemark is selected, the info pane slides into view, this is a subtle scale transition in which animation calls the user's attention to the shift in scales. The info pane is scrollable, taking advantage of the affordances for manipulation in figural screen space, and playing a video or selecting an image here calls up the media player in the center of the screen, these are also figural scale elements (Figure 4.8).

Figure 4.8. Video player activated from info pane.

In the observation of analog tour users, described above, I noted that many tour participants referenced the figural scale written materials while walking the tour route. However, these materials were not tied specifically to the location in which they were accessed. By providing information that is directly tied to the immediate context, the GTour application overcomes this limitation of the analog tour and coordinates information and representations across the panoramic and figural scales. This gives users context-relevant information that is directly tied to the panoramic space, much the same way the tour guides specifically point out and reference objects at "stop-and-talk" points. In this way, the MR tour simultaneously preserves an aspect of the analog tour, while also overcoming one of its shortcomings, helping to preserve the *continuity* of information across scales.

There is an additional icon available in panorama mode as shown in Figure 4.9.

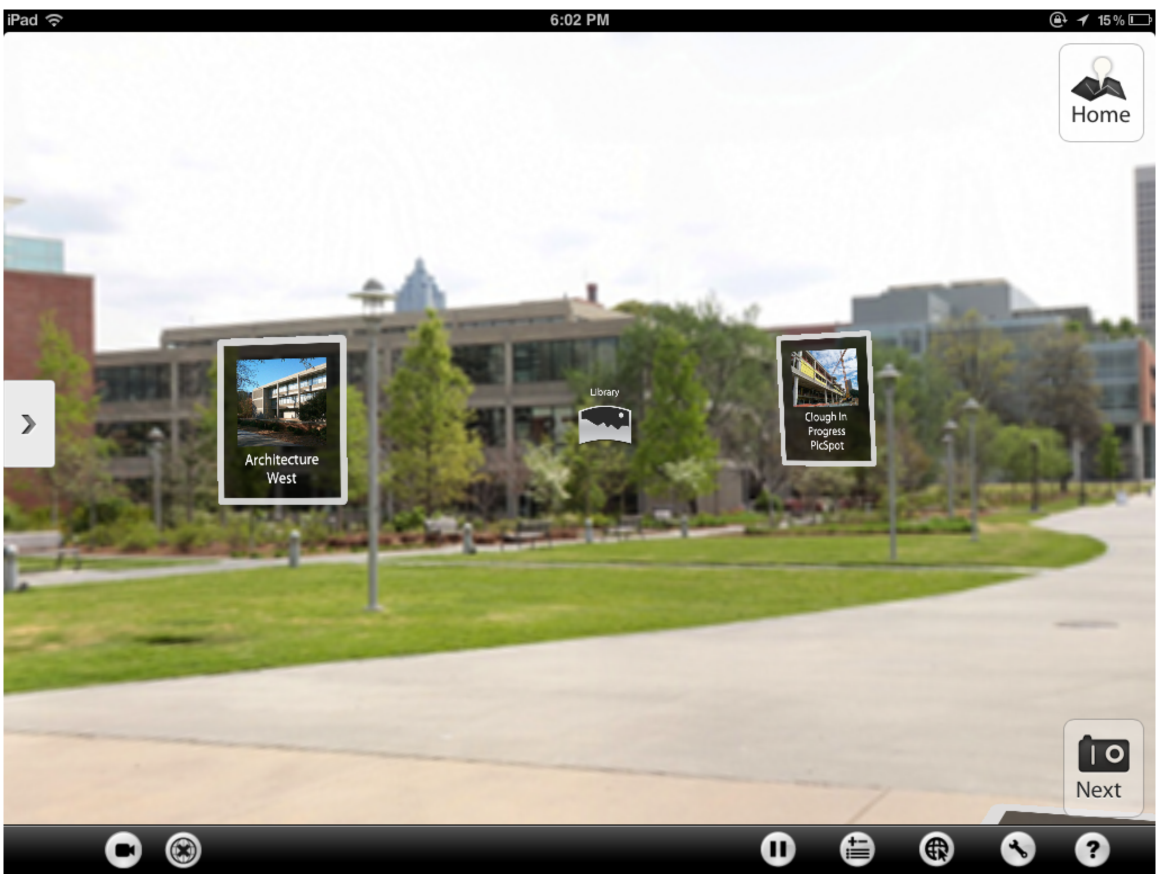

Figure 4.9. Panorama Fly-to icon.

The icon in the center of Figure 4.9 is the same as the icons that denote the panoramic tour stops in Figure 4.1. This is again done in an effort to coordinate representations. In both cases the icons serve the same purpose, they exit the current panorama and load the selected one. This is done for two reasons. First, it enables a tour to be taken remotely if being present on campus is not possible. By allowing access to the different panoramic tour stops in this way, rather than solely through the map, the relative locations of each panorama are, potentially, more easily grasped by the remote user, it is yet another instance of *environmental approximation* at work. Having to return to the map screen to visit each panorama can be tedious; moreover, having a user randomly selecting panoramas can destroy the linearity therefore the continuity, of the analog walking tour that we are trying to preserve. GTour allows a tour curator to only show panoramic tour stops that are visible from the current location by limiting the range of stops shown in a panorama. For example, only showing tour stops that have been visited already, showing those within a certain distance, or only showing the next stop on a linear tour. This is a panoramic scale technique, relying on the boundaries set by human vision that gives the curator more control over how the tour is experienced. Forcing the user to only jump or "slide" from adjacent tour stops to visible ones, constrains interaction and gives a better sense of navigating a cohesive environment in a linear way, as was discussed in regard to the Walking Dead TV Companion application in the previous chapter.

One final point to make regarding the interface design in panorama mode regards the two icons located on the top and bottom right corners of the panorama. The top icon returns to the map screen, and the bottom icon enters camera mode where the same 3-D arrow seen in figure 4.4 directs the user to the next stop on the tour. This functionality can also be customized using javascript to point to the next closest stop, in addition to one predetermined by the curator.

4.4 System Description

All components of GTour, the tour itself and the curatorial web-tools, are dependent on a campus-wide infrastructure, *GTmob*, which is unique to Georgia Tech. Although this infrastructure and the services it provides are not commonly available, they make use of common web-based architectures and technologies that are widely used. These include:

- a *mysql* database custom designed to host and support the tour itself
- commercially available databases and content management systems currently in use by other campus organizations such as the Georgia Tech library archives, Alumni Association, Capital Planning and Management, and Office of Housing, that host data reappropriated for the tour
- php accessed through a RESTful interface
- the Argon browser

All of these technologies are available for those who wish to create the tour as it was designed, however, the collection and implementation is necessarily unique to Georgia Tech.

4.4.1 The Database

The database is the backbone of GTour and its associated tools, and so it makes sense to begin our exploration of the GTour architecture there. However, to say that GTour makes use of one database is not entirely accurate. Resources, such as images, text, video, and audio, the whole of the tour content, are stored on different systems run by different campus organizations, and are not under the direct control of GTour framework. This is an important concept, as it means that curators of specific content types, such as the archivists, marketers, and student organizations still maintain control over their resources and can update them as needed. For example, an image of the current members of a particular fraternity can be changed on the fraternity's own server as old members graduate and new ones join. These changes will be reflected immediately in the tour, provided the URL does not change, keeping the experience up-to-date. More importantly though, this prevents the need for the tour to be centrally curated and constantly updated on a continual basis. Essentially, the content of the tour is, in large part, distributed throughout the community.

Databases not only store information, they also represent the relationships between that information. Tables in the database are of two distinct types, either they define representations at a given scale, or they relate representations at different scales. The table below summarizes the database. Note that the name "photo" appears here because all content was originally intended to be photographs, but relabeling the tables more appropriately as "content" or "media" was too complex once the database and all supporting infrastructure was built, so the term "photo" remains as a vestigial structure.

Table Name	Function
panoramas	Relates a panorama to the environmental space using GPS coordinates
panorama_images	Defines the 6 cube face images that make a panorama
panorama_pois	Relates POIs to a panorama with position and orientation information
photos	Defines the content (currently only images and text)
photo_images	Stores any content images that require local hosting
photo_tags	Relates content to keywords
pois	Defines points of interest
poi_photos	Relates a POI to a piece of content
tags	Defines the keywords associated with content
tours	Defines a tour with a unique ID, title and description for home screen
tour_panoramas	Relates a set of panoramas to a given tour
tour_panorama_pois	Relates the POIs to a specific panorama-tour combination

tour_pamorama_pois_photos	Relates the info pane content to a given POI-panorama-tour combination
tour_panorama_pois_tags	Defines the tags to be used in a given tour-panorama-POI combination (used for editor only)

Table 4.1. Description of database tables for GTour application

As the panoramic tour stops are the heart of the tour experience I will begin the discussion there. The first table listed above, **panoramas**, contains the location of a panorama at the environmental scale; that is, at the level of the campus itself. These are the coordinates that appear in the map view of the GTour application. A snapshot of this table appears in figure 4.10.

+ Options

←T→	panorama_id	title	description	latitude	longitude	altitude	heading	tilt	roll
Edit Copy Delete	1	Ferst & Fowler		33.776855	-84.39373	0	0	0	0
Edit Copy Delete	2	5th & Techwood		33.77681	-84.392204	0	0	0	0
Edit Copy Delete	3	4th & Techwood North		33.775436	-84.392052	0	0	0	0

Figure 4.10 panoramas table from GTour database.

This table also gives each panorama a unique numerical id, the panorama_id serves as a key for the next table in the list, **panorama_images**. This table contains the actual images used to create the panorama as six faces of a cube rendered as a skybox surrounding the user. This is shown in figure 4.11 below.

←T→	panorama_id	side	mime_type	mtime	blob
Edit Copy Delete	1	front	image/jpg	2012-05-29 12:27:59	[BLOB - 963.6 KiB]
Edit Copy Delete	1	back	image/jpg	2012-05-29 12:29:37	[BLOB - 965.9 KiB]
Edit Copy Delete	1	left	image/jpg	2012-05-29 12:30:36	[BLOB - 889.7 KiB]
Edit Copy Delete	1	right	image/jpg	2012-05-29 12:31:26	[BLOB - 1 MiB]
Edit Copy Delete	1	top	image/jpg	2012-05-29 12:33:05	[BLOB - 577.1 KiB]
Edit Copy Delete	1	bottom	image/jpg	2012-05-29 12:34:03	[BLOB - 774.6 KiB]

Figure 4.11. Six faces of panoramic skybox defined in panoramic_images table.

Taken together, these two tables represent the panoramic tour stops at two different scales, the first at the environmental scale and the second at the panoramic scale itself. The panorama_id used as a key to relate the two database tables together also serves to relate or coordinate these representations at two different scales.

Similarly, other tables and relations in the database serve to coordinate between scales as well. Each placemark seen in a panorama contains an image and a label or title, these are referred to as “POIs” (Points of Interest) in the database and their associated information is stored in a table named **pois**, a snapshot of this table is shown in figure 4.12.

←T→	poi_id	title	base_description	base_image_url
Edit Copy Delete	1	College of Computing Building	This is the original building for the College of C...	http://gtalumni.org/map/images/buildings/coc.gif
Edit Copy Delete	2	Chandler Stadium	Russ Chandler Stadium is a college baseball stadiu...	
Edit Copy Delete	3	Architecture West	The West Wing of the architecture building was bui...	http://gtalumni.org/map/images/buildings/coaw.gif

Figure 4.12. pois table from GTour database.

This table defines each POI by giving it a unique numerical identifier, a title which appears under the image in the placemark and in the info pane, a base description which appears in the info pane if no other alternate description is given (more on this in a moment in regard to curating tours with the CTeditor widgets), and a base image url. As mentioned above, each URL is unique and points to a server operated by a campus organization independent of the GTour application. Although POIs are only visible as placemarks in panoramic space, you will notice that there is no column in the database table that relates a POI to a specific panorama. This is because POIs can be seen from a number of different vantage points, as part of different panoramic spaces, and potentially even labeled on a campus map (although there are too many to make this practical). POIs are an environmental scale construct and the association of a particular POI with a particular panorama is done through a separate table named **panorama_poi**, shown in figure 4.13.

+ Options

←T→	panorama_id	poi_id	latitude	longitude	altitude	heading	tilt	roll
Edit Copy Delete	1	2	10.1081	-29.5928	2.83768	386.141	0.214	-1.082
Edit Copy Delete	1	10	-2.91976	-10.0495	2.74853	178.2	-0.316	0.962
Edit Copy Delete	1	13	-6.94801	18.9265	4.32391	260.641	0.495	1.08
Edit Copy Delete	1	16	18.4731	8.6825	2.9226	264.626	0.851	1.533
Edit Copy Delete	1	86	-6.87171	-11.9934	3.46416	119.81	-3.27	1.176

Figure 4.13. panorama_poi table from GTour database

Where the **pois** table defines POIs at the environmental scale, the **panorama_poi** table defines their representation at the panoramic scale. Each POI has a position and orientation defined within a given panoramic space, denoted by the panorama_id column. In this way any POI can have multiple representations, defined by different coordinates, within a number of distinct panoramas. These tables map environmental scale content to panoramic scale space. It is also important to note that while the coordinate system used in the **panoramas** table are absolute GPS coordinates, the ones used in the **panorama-_poi** table are relative to the position of the camera. This point further cements the notion that this table defines a panoramic representation.

Any given tour made with the GTour system may want to include and exclude certain POIs or content. For example, a tour of Greek Life and Sports might want to exclude information about history or academics, and vice versa. This amounts to framing at the global scale, and is also seen in the relations among database tables. A tour is defined in the **tour** table, and has fields for a unique numerical identifier, a short internal title, and a description that appears in the info pane of the Home screen (shown in figure 4.1). This is a global scale representation. A tour is much more than this, however, it is also a collection of panoramic tour stops, commonly arranged in a linear fashion. The relationship between a tour and the panoramas it contains is accomplished by the **tour_panoramas** table, which simply associates a tour_ID with a collection of panorama_IDs. This allows a curator of any tour to determine which tour stops they want to include, and develop a tour route that leads the participant to the areas they want to see. The **tour_panoramas** table effectively defines an environmental space, as a collection of panoramic sub spaces. Given that the GTour system currently houses 20 panoramic tour stops, it is useful to be able to define subsets that focus on different themes, explore different areas, and can vary in the amount of time it takes to complete them. Every collection of panoramas, arranged into a tour, can work to create a different impression of Georgia Tech as a place at the environmental scale, by exposing participants to different aspects of campus life.

The table **tour_panorama_pois** takes the notion of tailoring a specific tour by constraining panoramas and applies it to pois. Where the **pois** table enumerates all possible POIs for a given panorama, the **tour_panorama_pois** table allows a curator to select only a subset of POIs to use as content in their tour. This essentially takes the global scale framing down to the level of panoramic space. Similarly, the **tour_panorama_poi_photos** takes this same framing down to the final level of figural space. Because the content in the **photos** table contains over 10000 pieces of content, it is not prudent to try and list all of them in the info pane. Limiting this selection on a POI by POI basis allows the curator to filter out content that is not relevant or does not contribute to the notion of "placeness" that they wish to convey in their tour.

4.5 The CTeditor

Beginning with the **tour** table, the **tour_panoramas, tour_panorama_pois,** and **tour_panorama_poi_photos** tables collectively embody the complete hierarchy of spatial scales in the database, and allow a tour designer to specify a tour at increasingly finer levels of detail. The tools that we have supplied to accommodate the design of tours are collectively referred to as the CTeditor. However, CTeditor is really a collection of web-based "widgets" that provide a user interface into the information contained in the database tables listed above. Despite being tied to the tables of the database itself, CTeditor attempts to present information the way a tour curator or designer might conceive of their tour, as a hierarchy of spatial scales.

The top-level page of the CTeditor, shown in figure 4.14, provides interfaces for two distinct roles. A "Tour Designer" is considered to be a individual who wishes to create a new tour by filtering information that already exists in the database. A "Curator" is someone with administrative privileges who is in charge of creating new content and maintaining the content that currently exists. Separating these roles was done partially as a safeguard, and partially as a means of simplifying each of the roles. After much experience with student projects, it was decided that we did not want the general student population to be able to alter the database in any permanent way. Doing so introduces the potential for errors that could potentially disrupt every function of the GTour system. Second, because GTour is designed to be an institute-sanctioned project, it is necessary to maintain some control over content and formatting to make sure that the values of the Institute are being upheld. So, while anyone can design a tour around any theme, the addition and alteration of content is centrally controlled by a small group of curators. As I have said though, the majority of the content is distributed throughout the institute and maintained by various student and administrative organizations. We assume that those organizations are policed for content by the institute itself and subject to its guidelines and bylaws.

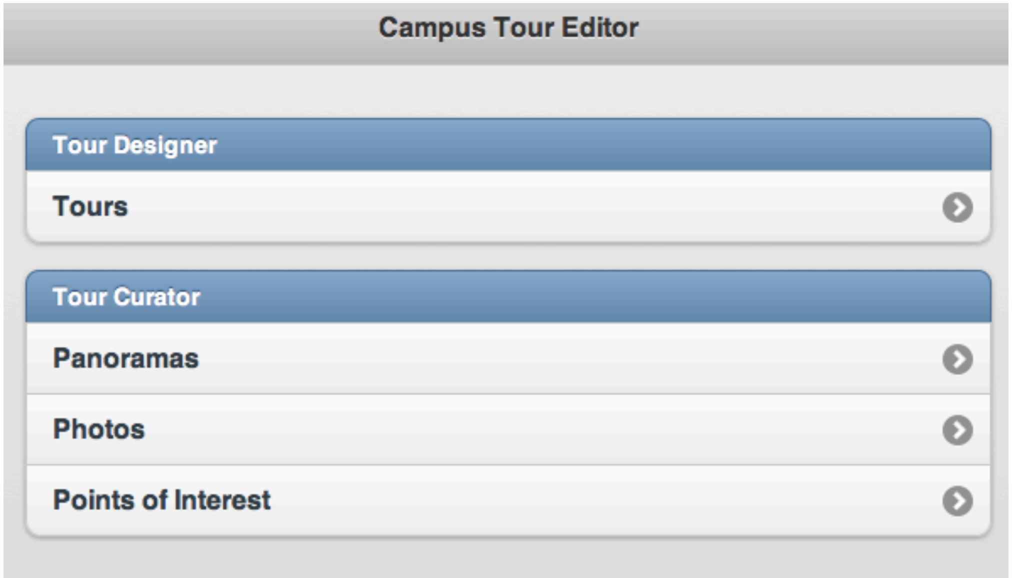

Figure 4.14. Main screen of CTeditor widget.

4.5.1 Tour Designers

The work of a Tour Designer begins with defining a new tour, or editing (choosing content) an existing tour that the designer has access to. Selecting the "Tours" button opens the screen shown in figure 4.15.

Figure 4.15. Three tours currently in the GTour system.

This screen presents the tour designer with a global scale view of their tour. Each tour focuses on a different aspect of life at Georgia Tech, or a unique perspective, such as that of the fictional character George P. Burdell. Initial global scale framing can be accomplished here, a food tour, an architecture tour, a housing tour, etc. Tour designers have the freedom to create a tour based on their own interests or the interests of their target audience and create a sense of place that is a unique reflection of their ideas.

After selecting a tour to edit, or creating a new tour, the designer is presented with the screen in figure 4.16.

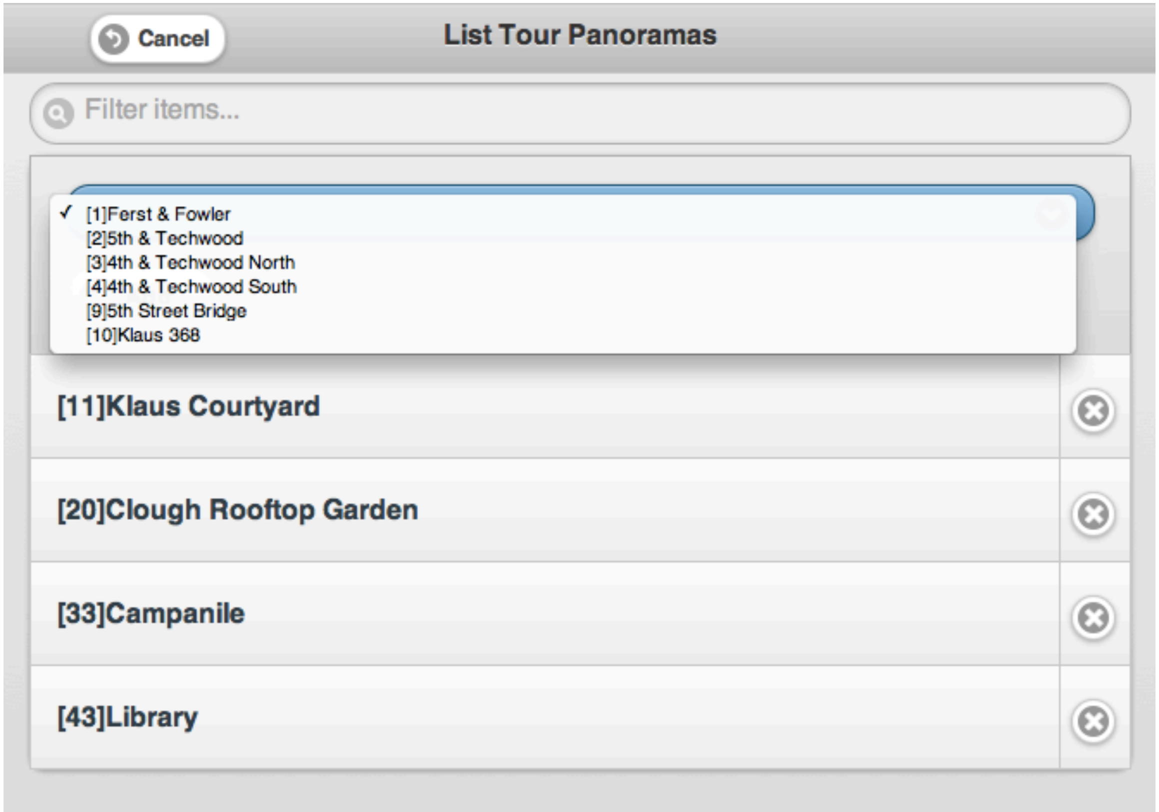

Figure 4.16. Panorama selection screen of CTeditor.

In keeping with the hierarchy of scales found in the MRSF, the panorama selection screen follows the global scale framing. As you would expect, this screen defines the panoramas that will be included in the tour. These are the same panoramas that will be represented on the map of the tour route and, as per the discussion above, aggregate to define the environmental scale of the tour experience. Figure 4.16 also depicts a drop-down menu that contains a list of all the panoramas not currently included in the tour. Selecting one of these panoramas adds it to the list of panoramas on the tour. The "circled X" next to each panorama's name deletes the panorama from the list. Selecting a panorama by name brings the designer to the screen depicted in figure 4.17.

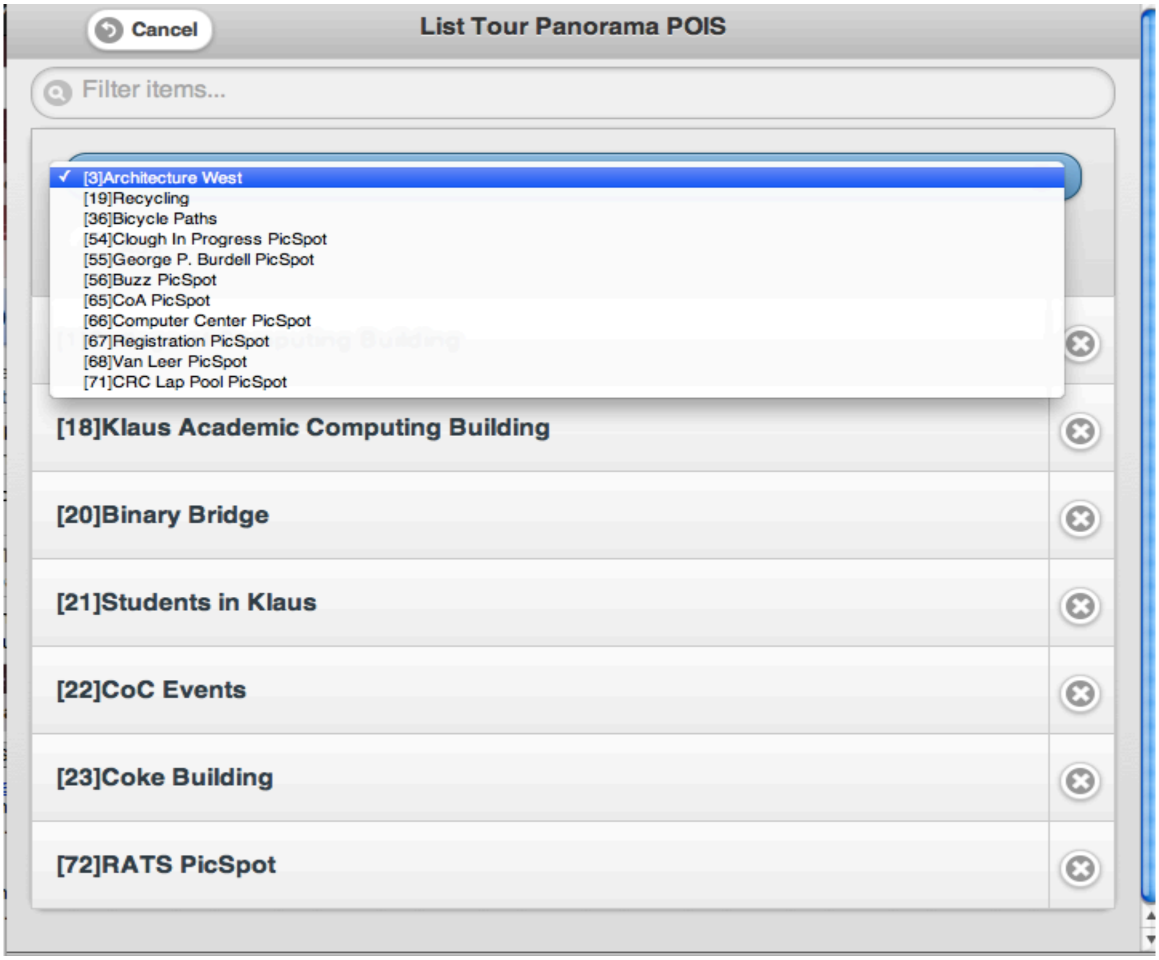

Figure 4.17. POI selection screen.

This screen is nearly identical to the panorama selection screen, and has identical functionality. However, the information it contains is now information about specific POIs, and is therefore one scale below the panorama selection screen. Here the tour designer can choose to include any and all POIs that a curator has associated with a panorama. This is another step toward filtering information to maintain the global framing of the tour experience. A designer of an academic tour may choose to limit POIs associated with non-academic activities, for example.

The final step in designing a campus tour using the CTeditor widgets naturally involves structuring information at the figural scale. This refers to the browsable content contained in the "info pane" of the application. As shown below in figure 4.18, this screen differs somewhat from the previous ones, as it has a slightly more complex job to do. While the total number of possible panoramas and POIs is small, on the order of a few dozen, the GTour database currently indexes over 10,000 pieces of content, mostly photos. For a typical tour, content should be limited to a reasonable amount of content for a given time period. With the average tour taking about an hour and consisting of 6 -8 panoramic tour stops, using all 10,000 pieces of content is not realistic. This portion of the CTeditor helps to filter that content to a reasonable level.

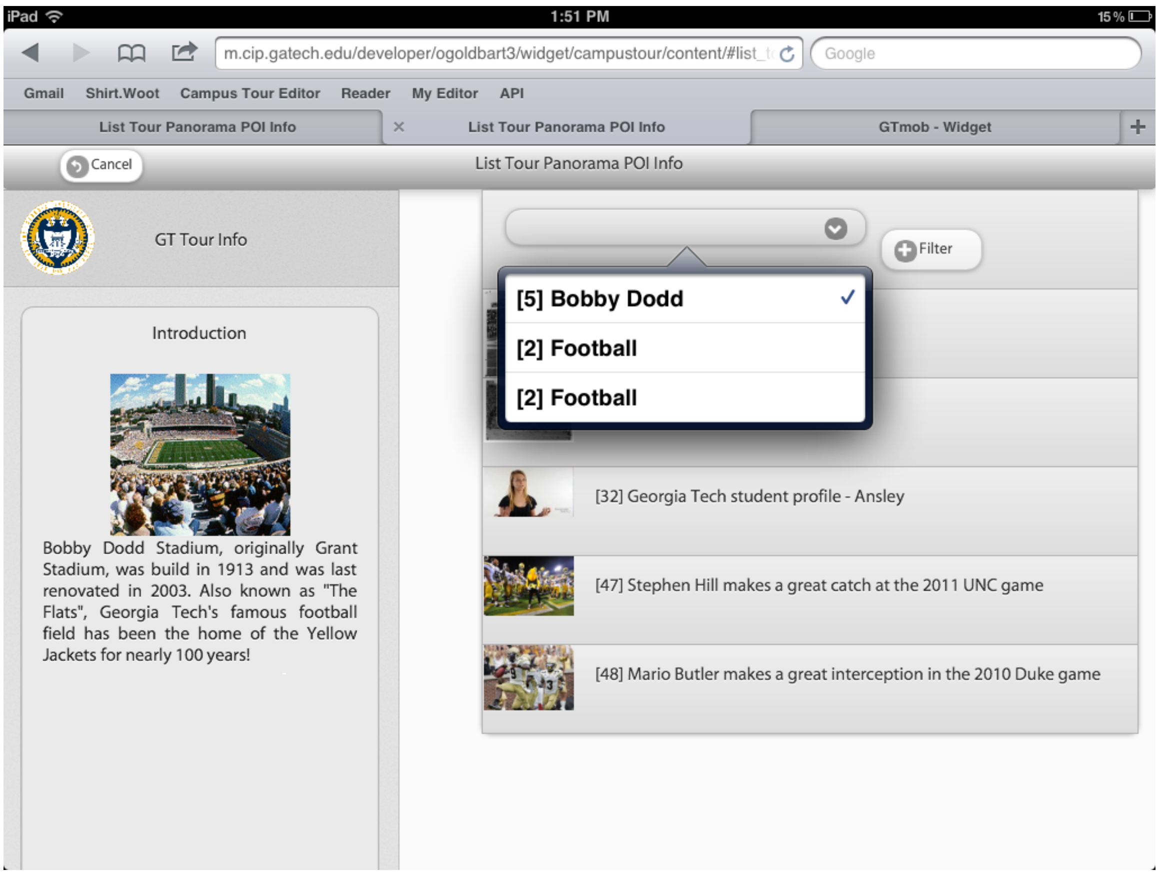

Figure 4.18. Content selection widget.

The first thing to notice is that the POI editing page consists of a WYSIWYG (What You See Is What You Get) style representation of the info pane used in the actual tour experience. This can help tour designers position the content in the manner they like best and preview the result. The right portion of the screen contains a dropdown for selecting content based on “tags” applied by a curator, as well as a browser to preview content before adding it to the info pane using a drag-and-drop style interface. The **tags** database table is controlled by a curator, although it would be possible to open this up to tour designers and even, potentially, the general student body. The **tags** table itself is simply a list of keywords that can be supplied by anyone with permissions to do so. Essentially, this is another means of global scale framing, not specifically of a tour, but of the content directly. The **photo_tags** table relates tags to specific photos, and this is the table that is accessed by the drop-down menu in the content selection widget. By choosing any or all tags a tour designer can filter the content displayed in the browser to a more manageable subset of the 10,000 total content elements. By using common keywords, and allowing others to supply their own, we not only filter content for easy selection, but also do so while maintaining global scale framing.

The final table to discuss, and the final tag-related table is the **tour_panorama_pois_tags** table. As the name implies it is four-levels deep in the spatial scale hierarchy, making it refer to figural scale objects. This can be confusing at first because I have discussed tags as being global scale elements, however, you must remember that these are used to describe the *content* that appears in the info pane, and therefore denotes a figural scale representation. This table was created to make tour maintenance scalable by specify a unique combination of content through four scales of hierarchy. By storing information at this level, we can easily reflect any additions to the database that might have occurred since the last time the tour designer logged in. For example, if POI 17 appears in panorama 3 of tour 5 then the next time the designer logs in to the system we can use all the tags they had previously selected, history and greek-life as examples, and notify them that additional content has been added. They can then navigate to the appropriate page of the content editor and decide if they want to include this new content. This makes the GTour application as a whole more dynamic and easily customizable in the long-run.

4.5.2 Tour Curator

The three sub-menus under the "Tour Curator" heading, panoramas, photos, and points of interest, are intended for content management by authorized personal only. Unlike the hierarchical design of the Tour Designer component, these three components provide a front-end to edit the database itself for editing information in the database, and were not developed to adhere to any notion of scale. Nevertheless, some hierarchical nesting can be seen, as the database itself contains elements at distinct scales. The first sub-panel, panoramas, provides a list of all the panoramas in the system, essentially a listing of the **panoramas** table. This can be seen in figure 4.19.

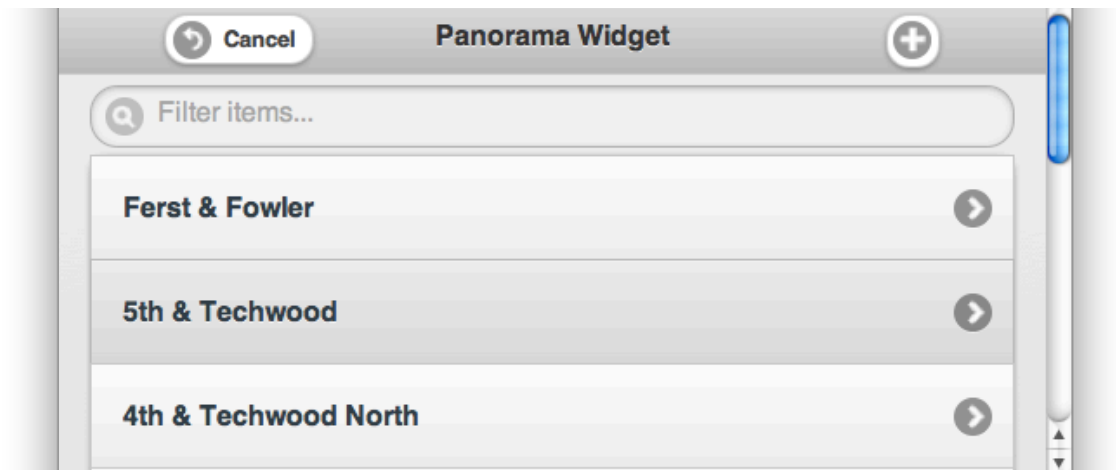

Figure 4.19. Example of panorama widget sub-panel.

Similar to the way the other widgets were designed, selecting an individual panorama opens an additional subpanel with the specific data for that panorama drawn from the various database tables. This sub-panel is divided into three sections seen in figures 4.20, 4.21, and 4.22. The first portion of the sub-panel provides access to the six cube faces of the panorama themselves, and users can upload these images here once they have been created in an external panoramic photography tool. Figure 6.14 shows the top portion of the panorama editing sub-panel.

The second section of the panorama editing sub-panel contains fields pulled from the database that describe the position and orientation of the panorama. These can be manually adjusted here to correct for any errors seen in the use and testing of the tour itself. Figure 6.15 shows this section of the sub-panel. Just below, shown in figure 6.16, is a list of all the POIs associated with this panorama. Similarly to the tour designer widget, a curator can use the drop down menu to add a POI to this panorama. However, while the tour designer is simply choosing to make a POI visible or not, this tool creates the initial association between a POI and a panorama, making it available in the drop-down menu used by the tour designer as described above. Selecting a POI from this page directs to another sub-panel that contains the position and orientation information for the POI placemark in this specific panorama, for purposes of editing.

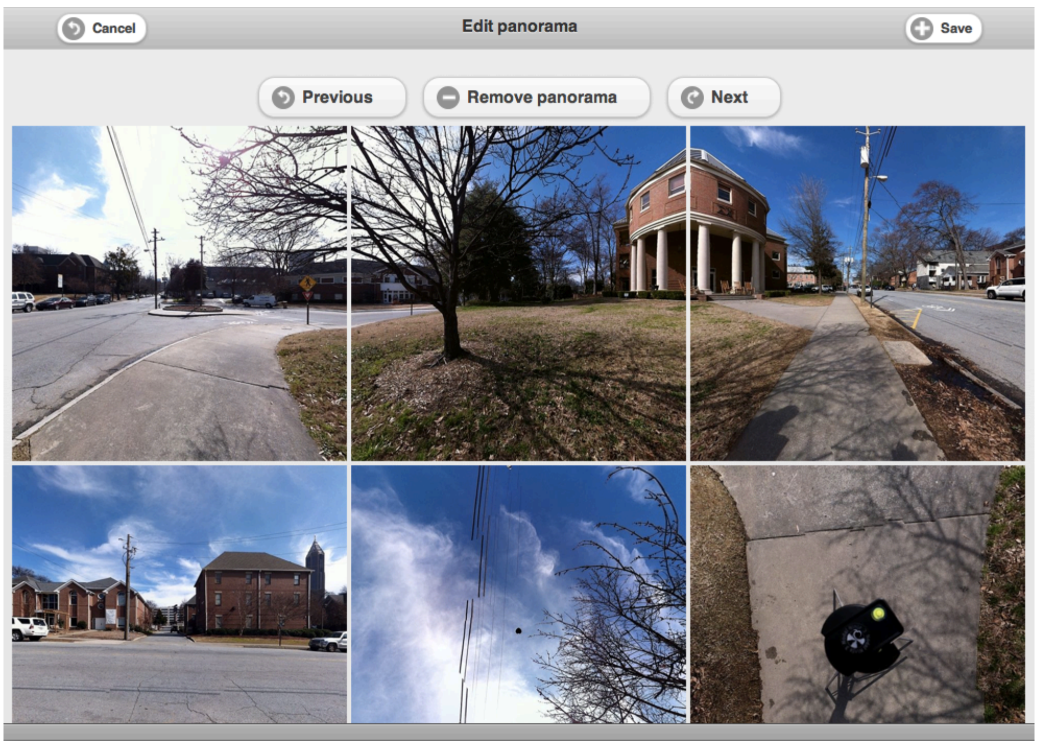

Figure 4.20. Panorama cube faces as seen in panorama editing widget.

Figure 4.21. Details of individual panorama in editing sub-panel.

Figure 4.22. POI listing from panorama editing sub-panel.

The additional sub-panels accessible from the main screen, photos and points-of-interest, also provide direct access to the database tables allowing curators to add urls for content, write and edit the text descriptions that accompany this content, and import new content that needs to be hosted on the GTour server.

4.6 The Positioning Tool

The final component of the suite of web tools built in association with GTour is the Positioning Tool. Unlike the CTeditor widgets that are primarily web-based, the Positioning Tool works using the Argon Browser. The function of the Positioning Tool is to let a user adjust the position and orientation of individual placemarks to achieve tight registration within a specific panorama. A screenshot of the tool being used to position a placemark within a panorama can be seen in figure 4.23.

Figure 4.23. Positioning Tool being used to place CoA PicSpot placemark.

The Positioning Tool has a number of features. In the top left are two dropdown menus that are used to select the panorama and POI that the user wants to place. These are drawn directly from the database. When the user selects a panorama in the menu, that panorama is loaded in Argon along with all of the placemarks that have already been positioned. This allows the Positioning Tool to function as a WYSIWYG style interface to the database where a user can position placemarks in the panorama and preview what the final result will look like in the actual tour experience. The dropdown menu for POIs works similarly, but where the panorama dropdown menu contains a list of all panoramas, the POI dropdown only lists a subset of POIs relevant to the panoramic space.

Controls, consisting of four slidebars, on the lower right side of the tool control the various attributes of the placemark. These are distance, measured in relative GPS coordinates with the camera itself as the 0 reference point; and heading, tilt and roll, measured in degrees with the center of the placemark facing the user as the 0 reference point. Manipulating these sliders achieves the results seen in figure 4.23, where placemarks appear to be registered on buildings, the floor, or on any other object that the user thinks is relevant. The use of relative GPS coordinates here, and in the tour itself, is interesting because it is a direct result of being in a pre-defined panoramic space. Absolute GPS coordinates could also have been used, and would have been the only choice possible if the user were permitted to use the "camera" on the device in real-time. However, GPS coordinates are too error-prone to achieve the tight registration seen in the images of the tour and tool shown above. Given this technological limitation, using relative GPS coordinates was the only way to achieve the desired result. In working with the team programming this tool, I often found some confusion regarding the terminology "absolute" vs. "relative" coordinate systems, as the programmers (mostly undergraduates) typically thought of "relative" GPS coordinates as variable, while "absolute" was synonymous with "permanent." To alleviate this confusing, I began referring to the absolute GPS coordinates of the panoramas on the map as "environmental" GPS coordinates, and the coordinates of the placemarks within a panorama as "panoramic" coordinates. Although these students were unfamiliar with the scales of the MRSF, they found these names to be more intuitive, and they became our default terminology.

The last portion of the Positioning Tool consists of the two buttons in the lower left corner of figure 4.23, labeled "set placemark" and "fix placemark." The set placemark button is used to upload the distance, heading, tilt and roll values into the **panorama_**pois table. The fix placemark is available if the user wishes to adjust a placemark that has already been set. By clicking on an existing placemark, and pressing the fix placemark button, the user can freely adjust that placemark's attributes and press the set placemark to overwrite the existing values. Although the words "fix" and "set" are unfortunately similar in meanings at times, "fix" in this case is meant in the sense of "fix something that is broken." The term is slated for a change in future iterations for clarity.

One final point about the Positioning Tool came from on observation of two of our tour curators who were using it to place content. Although multiple instances of the tool can be used on separate iPads simultaneously to place content, these curators elected to use a single device and work as a team, as shown in figure 4.24 below.

Figure 4.24. Tour curators using the Positioning Tool

As you can see, the curators have taken on separate rolls with one doing the physical adjusting of the placemark using the positioning tool and the other directing the placement. This suggests that there is some cognitive work that is potentially too difficult for one person to do on their own. The user in the chair is working in the figural space, his attention is focused on the manipulation of the controls using the touchscreen, while the second curator looks over his shoulder and gives directions about what adjustments need to be made. It is likely the case that splitting attention between the figural control space and vista where the actual placemark is being positioned is an overwhelming cognitive load for one person. Indeed, when I used the tool myself I found it difficult to attend to both consistently and made many errors. These finds, although only anecdotal at this point, strongly suggest that splitting attention between tasks at spatial scales is difficult and should be designed around if possible.

4.7 User Study with Middle School Students

4.7.1 Overview

The central questions of this thesis revolve around how spatial scale enters into human thinking in the context of MR experiences, and what we can learn from its influence there. This includes the use of MR experiences as well as design. In the previous chapter I explained how users of [inbox] showed clear evidence of wanted some kind of a connection between scales, which suggested the notion of coordinating representations between them. This section continues in the same vein, investigating the role of scale in users of the MR walking tour. This study took place in the context of a day-long visit of 30 middle-school students from underprivileged schools in DeKalb County Georgia, who were attending a summer camp on the Georgia Tech campus. The fact that these students were new to the Georgia Tech campus, and alarmingly naïve about college in general made them potentially a valuable source of information regarding the effectiveness of the GTour application. As they had very few preconceived notions of what the tour experience was supposed to be like. The study in which these students were involved occurred over the course of a day with an hour of their morning session devoted to using the GTour application during a walk around the campus as a group, and an hour in the afternoon devoted to 3, twenty-minute long, focus groups involving 10 students each.

4.7.2 Evidence of Scale Thinking

There was evidence from this study that suggests scale thinking was at work. One student in a focus group mentioned that it did not make any sense to her to have a placemark describing the football stadium in a panorama taken outside the library, where the stadium was not visible. While on its own this observation is not particularly compelling, however its relation to scale represents an important design guideline that is ignored with surprising frequency. The inclusion of the stadium placemark in the library panorama was an error that we did not notice when creating the tour, therefore it broke the design guideline of only including representations of the visible surrounding space, which was our attempt to preserve the spirit of the "stop-and-talk" points. The fact that this participant was confused by this error furthers the validity of and utility of this design guideline. Yet, even commercially available AR applications, like Yelp for example, don't do this as the default. Technologically, this is much more difficult than simple limiting a list by number of responses or distance but it is an important consideration nonetheless, as panoramic space is limited by line-of-sight.

A comment by another subject, although not specifically related to scale, does have implications for multi-scale design. In a response to a question about what aspects of the tour were broken or "buggy" one student mentioned that the map on his device was broken because as he moved forward the flashing buzz icon representing his position moved to the right. Of course, the map was not broken, and the GPS sensor was functioning correctly, this student was simply having an issue with egocentric vs. allocentric space. He thought that because he was moving straight-ahead that the map should have been automatically oriented to his egocentric perspective, making forward in the world appear to be up on the map. There is nothing wrong with this view, clearly enough people orient themselves this way for Google Maps to include dynamic map rotation as a feature. However, it does suggest an interesting variable that could be tested in future experiments.

There was also some fairly obvious indication of scale thinking occurring during the tour, simply because the tour itself requires scanning the panoramic space in order to select a placemark, and then reading information about that placemark. Subjects did not object to this style of interaction, and found it largely intuitive. Additionally, I was able to observe a number of subjects using the tour to access information about the building they were oriented toward, and their behavior seemed to suggest that they were in fact using the application effectively. They would hold the device in front of them, select the placemark, and then read the accompanying text. Interestingly though, some users, like the ones depicted below in figures 4.25 and 4.26, would consistently and frequently look up at the physical world while reading the text. This is similar to what one would expect in if they were coordinating representations during navigation, but they weren't navigating. In seems, there was something much more conceptual going on. It's almost as if they were checking the landmark to see if had changed in any way, or to be sure it was still there. It was almost as if the acquisition of new information needed to be confirmed by seeing the landmark, or that gaining new information made them try to see it in a different light. Shore might even suggest that as their internal representation of the landmark changed, that it needed to be coordinated with the external representation. No matter the reason, this is an interesting behavior that we might not have observed without sensitivity to scale and suggests some further research that might help illuminate how make process the combination of virtual and physical information.

Figure 4.25. Two students comparing descriptions during their tour experience.

Figure 4.26. Subjects using GTour. The subject on the right is re-examining a landmark after reading its description on the device.

One final observation related to scale has to do with the behaviors in panoramic spaces. Due to the fact that the whole tour group would stop at the same locations, it was impossible for everyone using the tour to stand at the exact position where the panorama was shot. Interestingly, this did not seem to be an issue, and many subjects simply used the tour from wherever they happened to be, with no obvious difficulty. In fact, no one even asked where they were supposed to stand, and no one seemed to even try to locate the correct location. This suggests that it matters very little where one stands when using the panoramas for this kind of informal learning experience. Future research might attempt to determine the exact distance or perspective at which using these canned panoramas becomes problematic and exactly what factors play a role in determining those effects.

4.7.3 Social Aspects

Social aspects surrounding the use of GTour dominated this experience. These are not particularly relevant for our discussion of scale, but I want to examine them nonetheless because they are can still offer some valuable insight into the design of these experiences. For one, some subjects were "device hogs" they kept a device until explicitly asked to share it, and then waited only very short periods of time before obtaining another one. Others were "device-phobic" and showed no interest in even holding a device. The majority of hogs were male, while the females most often shunned the devices. One group of girls formed a clique almost immediately upon starting the tour and simply walked the tour route socializing with each other, never asking for or using a device.

Subjects who used the devices tended to break into smaller groups of 2-4 people, using one or two devices. The boys in figure 2.25 and 4.26 were device hogs who took the whole tour together, often sharing information and pointing out landmarks to each other. It was clear that these two were the most engaged with the tour and the fact that they were able to use their own devices while walking together seemed to reinforce their engagement with the experience. Other groups of approximately 5-6 subjects, often only females, and sometimes with mixed genders also formed. These groups tended to use one device and to pass it around. Often though, the conversation was not about the tour, but focused on external factors, with the tour as a backdrop and sometimes a distraction. Figure 7.8 shows one of these groups. While it is not clear whether this was due to a lack of devices or other social factors, it is certainly something that can affect tour engagement and should be accounted for in design.

Figure 4.27. Group using single GTour app.

When the group stopped at a panorama point other interesting group dynamics emerged. For one, there was much more sharing involved when everyone hovered in the same space. Devices were passed more freely from person to person, and information from the tour was also passed along, with the number of books in the library a frequent topic of conversation. This observation could potentially be accounted for by scale as well. Just as in the analog tour, where groups would stop reading the written materials when they stopped at a panoramic stop-and-talk point, participants on this tour also changed their behavior at these panoramic points. Interestingly, the exhibited the opposite behavior than those on the analog tour, instead of focusing attention away from the figural scale and into the panoramic space, these participants divided attention between the two scales more readily. Given that one design goal of the MR tour was to more closely tie panoramic and figural scale representations together at these panoramic tour stops, the observed behavior suggests that this design goal was successful.

Figure 4.28. A group sharing devices at a panorama point.

4.7.4 Limitations of the Study

There were a number of confounding factors that made it difficult to find much compelling evidence regarding the role of scale in the use of the GTour application with these subjects. For one, there were technological roadblocks. Only 8 iPads were available for the 30 students and 8 instructors to share during the experience, and as many as half of these did not perform consistently, making the availability of the tour spotty for the duration of the experience. There were logistical roadblocks as well. Immediately before the tour, for reasons of convenience, the head instructor decided that they wanted the tour to take a different route than the one planned for the study. This limited the number of panoramic spaces that could be viewed in-place as part of the tour. The most important confounds revolved around the students themselves. Many of the students had never used an iPad before, and when they were given their device this inexperience manifested itself in a number of ways. For one, they often pressed buttons unwittingly and exited the application accidentally. Also, some were so excited to have one of these devices that they began to explore it thoroughly, opening and closing applications and using the internet. These served to distract them from the tour. Furthermore, many students were simply excited to be in a new environment with their friends that they wanted to enjoy the sunshine and took the opportunity to socialize. The other major confound had simply to do with the maturity and sophistication level of these students. Although they often showed evidence of being capable of great insight, the capacity for self-reflection was inconsistent. This was partly a function of age, students were 10-12 years old, and there was a great disparity between the cognitive capacities of the younger and older students. Here too though, social factors also came into play, with many students reticent to speak or ask questions and instead preferring to appear not to be engaged, presumably to avoid some unspoken social stigma. The combination of these factors made it difficult to extract anything more than anecdotal data. Nevertheless, there were some useful experimental findings regarding scale, and, because these factors were dominant, some very interesting social behaviors that pointed toward interesting potential future research questions.

CHAPTER 5

A LANGUAGE OF MIXED REALITY

IN THE CONTINUITY STYLE

In the previous chapter I discussed the MR campus tour primarily in terms of its spatial components, and argued for basing our understanding of this essential aspect of MR experiences on the concept of spatial scale. However, while MR walking tours do make fundamental use of space, they are not solely spatial experiences. These experiences, and presumably all MR experiences, are also intended to be personally meaningful for their users. To that end, the MR walking tour serves as a useful example in another regard, as means of delivering experiences that communicate a sense of *place* as well as a sense of space. In this chapter, I argue that both place and space operate at the scales of the MRSF, and that the ability to account for both of these makes the MRSF an excellent starting point for beginning to develop (or discover) a "language" of MR similar to the languages used to discuss older forms of media, film most notably. Just like in film, such a language serves the purposes of outlining the formal elements of communication used to construct MR experiences and offers a common baseline for talking and thinking about the structure of MR experiences, that extends beyond the walking tour. Rather than drawing any firm conclusions or prescriptions for understanding and building effecting MR experiences, I introduce this discussion as an exploration of concepts and connections that suggest the possibility of a pattern language for MR, in the hopes that elucidating these will prompt enough interest to further exploration and inquiry.

5.1 Walking Tours and Cultural Heritage

The structure of an analog walking tour is always very similar. A participant follows a mostly pre-determined path, a *trajectory*, through the environment, stopping at various points of interest along the way. Traditionally, there is a human tour-guide, but increasingly these tours are self-facilitated and digitally augmented. While this overall structure is most closely associated with *cultural heritage*[1] experiences, it can easily be generalized to situations such as a building inspection, a real-estate open house, worker orientation, etc., making any knowledge gained from understanding the MR walking tour potentially applicable to many of the other domains where MR intervention has been proposed, suggesting that a language of MR rooted in these experiences is also applicable more generally. In cultural heritage tours information is often arranged thematically, framed at the global scale to construct a particular view of the world. Points of interest are curated into a collection by category, such as art or architecture, historic periods or people, or some other topic of interest, just as was proposed in the development of the MR campus tour. This requires that these experiences deliver information that is spatially organized, but culturally meaningful as well; this is where MR technologies are potentially the most useful, but also where they have most obviously fallen short (Barba et al., 2012).

The technological mediation of spatial experience through the use of virtual elements is the defining characteristic of MR applications; all conceptions of MR agree on this point. However, the human experience of space, particularly where cultural heritage is concerned, requires the integration of the physical components of spatial interaction (walking, pointing, standing, touching, etc.) with the social and cultural contexts that make interaction in these spaces meaningful (What am I touching? Why am I standing here?). These two elements, what many researchers have distilled into the concepts of "space and place" (Dourish, 2006, Fitting et al., 2007, Harrison and Dourish, 1992, Tuan, 1977), meet not only in the external, observable world, but also within the human mind itself. Therefore, any successful framework for the design and analysis of

[1] I adopt the UNESCO definitions of intangible and tangible cultural heritage defined in (UNESCO, 2003)

MR must be able to account for both the physical arrangement of space, and the conceptual elements that make any space a meaningful place; in the mind and in the world.

5.1.1 Space and Place

Designing and analyzing MR walking tours requires a framework from which we can reason about the relationships between the spatial and place-based (platial[2]) elements of these experiences, as well as the role technology plays in mediating between them. The relationship between space and place has been well-theorized in various disciplines. The seminal work on space and place was written by the geographer, Yi-Fu Tuan. In the same vein as this discussion, Tuan is concerned with the relationship between space and place as components of human experience, which is inextricably wound up with the way ordinary space becomes meaningful. Tuan summarizes this point nicely:

> What begins as undifferentiated space becomes place as we get to know it better and endow it with value.
>
> (Tuan, 1977, p. 6)
>
> Space is transformed into place as it acquires definition and meaning.
>
> (Tuan, 1977. p.136)

While it is certainly true that culture has a tremendous impact on what does or does not make something meaningful, rather than adopting the view that place is a cultural construction while space refers to a physical one, Tuan posits a more complex and nuanced relationship. He notes that as biological beings inhabiting space, and developing in the same evolutionary stages, there must be some common experience of space achieved through our physical bodies that unites all human beings, independent of culture. Still, culture is always a part of spatial experience, particularly when that experience is given meaning as place. Nevertheless, I want to be mindful of the

[2] I will not adopt the term “platial” in this work, because it is somewhat jarring. However, I do wish to point out that such a word to describe the attributes of place does not exist in the English vocabulary the way that spatial, or facial, or racial, etc. do. I invite the reader to ask why this is the case and to adopt the term “platial” when it suits their needs.

potential that there is an essential, even biological, human need to make spaces into meaningful places that precedes enculturation and is simply emphasized and extended by culture. This conception is encapsulated in Tuan's notion of experience, which he views as multi-modal; that is, comprised of different "modes" that include "sensorimotor, tactile, visual, and conceptual." Tuan's definition of experience, a definition that I will adopt as well, incorporates all of these in a holistic fashion:

> Experience is a cover-all term for the various modes through which a person knows and constructs a reality. These modes range from the more direct and passive senses of smell, taste, and touch, to active visual perception and the indirect mode of symbolization.
>
> (Tuan 1977, p. 8)

While mobile technology has not developed the capacity to readily influence senses like taste and smell, it nonetheless has become an integrated and often transparent extension of everyday life. It is very much involved with delivering tactile, visual, and symbolic representations. These direct (somatic) and indirect (symbolic) modes of experience, ways of knowing and constructing mixed realities, have not yet been fully articulated in the discourse surrounding MR.

5.1.2 A Cognitive Approach

Both somatic and symbolic modes of experience are functions of the human nervous system and the human mind, and so the perspective offered by the cognitive and neurological sciences is one that needs to be accounted for. This is particularly salient in the context of Tuan's belief in an essential and pre-cultural experience of space. The view of experience articulated by Tuan, in which somatic experience integrates with symbolic experience, anticipated a theoretical move in cognitive science made by Lakoff & Johnson some years later when they introduced their notion of *embodied cognition* (Lakoff and Johnson, 1980). That theory posits that higher-order symbolic meanings can almost always be traced to lower-level sensorimotor "schemas" that are formed from direct physical experience. These schemas are stored in human memory and are connected or "mapped" onto new situations through the use of analogy and metaphor. The results are what we refer to as categories, concepts, and meanings; or, more generally, the organization of the mind associated with indirect symbolic interpretation. Appropriately, space and spatial metaphors serve as a common source for constructing meaning in higher-order symbolic concept formation and are fundamental to the theory of embodied cognition.

Embodied cognition offers an important theoretical touchstone that connects cognition explicitly to Tuan's notions of space and place, and highlights the potentially important role played by analogy and metaphor in understanding modes of experience in MR. However, cognitive science has still more to offer, as the integration and representation of information about place and space is addressed specifically in the literature surrounding *cognitive maps*. Although many researchers focus solely on the spatial qualities of cognitive maps, defined casually as, "the way people represent the world in their heads," others have also recognized that much of the spatial information contained in these cognitive maps is meaningful because of the cultural and personal significance attached to those spaces. In a sense, cognitive science has its own version of the space and place distinction:

> …cognitive map[s] include knowledge about places as well as knowledge consisting of spatial relationships.
>
> (Kaplan., 1976)

Other researchers concur, but use slightly different language and definitions to make their point. For example, Kitchin describes cognitive maps as the combination of "environmental cognition with spatial cognition" (Kitchin, 1994). There are established definitions of these two categories of cognition. Spatial cognition is summarized nicely by Hart & Moore:

> ...the knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought.
>
> (Hart and Moore, 1973)

While the idea of environmental cognition, summarized by Moore and Golledge is more closely aligned with the notion of place:

> …the awareness, impressions, information, images, and beliefs that people have about environments… and that they imbue them with meaning, significance, and mythical-symbolic properties.
>
> (Moore & Golledge, 1976, p.3)

Clearly cognitive maps are an amalgam of spatial and place-related information. They are conceptual constructs that exist in the mind, derived from both direct physical experience and indirect symbolic systems.[3] Following the work of Johnson-Laird (Johnson-Laird, 1983), who notes that cognitive maps played an important historical role in the development of the notion of *cognitive models*, I conceive of cognitive maps as cognitive models of space and place, rather than as isolated constructs. This approach has much to recommend it, particularly where MR is concerned.

By using the phrase "cognitive model" I mean to refer to a number of distinct but interrelated ideas. First, I mean to denote a *mental model* (Gentner et al., 2001, Norman, 2002, Johnson-Laird, 1983) that participants and designers of MR experiences use to reason about their structure, operation, and content. Like any theoretical construct, mental models have been defined in slightly different ways, at different times, by different authors, for different purposes. When I talk about mental models in this work, I mean simply, "a representation of reality in the mind." Such a loose definition will unavoidably draw the ire of researchers in many fields where a more specific definition

[3] Kitchin also recounts a number of differing philosophical views on the nature of cognitive maps that are all variously in play in the cognitive science community. One view holds that they are actual, 3-dimensional, cartographic maps that exist in the neurons of the brain (O'KEEFE, J. & NADEL, J. 1978). Another view holds that they are highly compressed representations that function like maps, but are not actually maps in the cartographic sense (KAPLAN, S. 1973). Still another view finds that they are just an idea with no real connections to maps at all, other than as a convenient analogy used to organize and make sense of how the mind conceives of space (KAPLAN, S. 1973).

differentiates their work and expertise. Still, this general description does encompass many of the differing ways the term has been used throughout its lifetime (Davidson et al., 1999) and captures the purpose of using such a term in the first place. Mental models are not only found in the heads of users, however, they necessarily exist in the minds of designers as well. This fact opens up an important line of inquiry where the idea of meaning is concerned, and is noted by Norman as a key point of convergence in the design of any technological system that makes it comprehensible to a user.

Mental models, by definition, exist internally, but this does not mean that the only evidence of them is internal as well. On the contrary, although not always explicitly stated as such, a number of authors have demonstrated that the rudiments of mental models can be seen externally in cultural artifacts, and suggest that any internal mental model is derived from physical experience situated in a cultural context (Shore, 1996, Bolter and Grusin, 2000, Manovich, 2002, Norman, 2002). Tuan also recognizes this fact in regard to space:

> Human beings not only discern geometric patterns in nature and create abstract spaces in the mind, they also try to embody their feelings, images, and thoughts in tangible material. The result is sculptural and architectural space, and on a large scale, the planned city. Progress here is from inchoate feelings for space and fleeting discernments of it in nature to their public and material reification.
>
> (Tuan, 1977, p. 17)

In this complimentary view, designers can be thought of as embedding or embodying their mental models in the artifacts they create. This is how designers construct compelling and meaningful experiences, experiences that can be *made sense of*. This point suggests that any framework for the design and analysis of MR experiences must take into account the relationship between cognitive models in the mind and those embedded in the artifacts and practices found in the world, what anthropologists refer to as *cultural models.* Such artifacts and practices are also commonly referred to as the *tangible* and *intangible* components of cultural heritage. The cognitive and cultural models I consider here are primarily spatial in nature, but have personal, cultural, and conceptual elements that take embodied forms during the design process. They are models of place as well as space.

5.1.3 Sense-making

I take the view that the relationship between mental models in the minds of designers and users, and cultural models in the world is mutually reinforcing. That is, mental models are formed in our heads through experience with cultural models in the world, and the cultural models we introduce into the world, as artifacts, are products of mental models. This hints at another connotation of the term "cognitive model," as a model *of* cognitive processes rather than a model *used in* cognitive processes. These are more typically the cognitive models used in Artificial Intelligence and robotics research. Although models of this type often strive to be so detailed that they can be implemented in computer programs, they must always begin with characterizations of human behavior and descriptions of the mental processes that produce that behavior. I will not posit any detailed model of the cognitive processes of users and designers of MR experiences, as that is beyond the scope of this work. Still, I do wish to borrow one, slightly higher-level, cognitive model of this type to explain the relationship between mental and cultural models, and to account for the important role of meaning in the creation of place.

As Tuan has suggested, the move from "undifferentiated space" to place often involves finding something significant in the experience; some kind of meaning. For MR experiences, meaning can be as complex as the social and cultural divisions between class and race that persist beyond the grave at Oakland Cemetery in Atlanta (Macintyre et al., 2004), or something as simple as knowing what nearby restaurant your friends go to for sushi. There are many theories of how the human mind creates meaning in different contexts. However, for the present purpose of understanding how MR can help transform space into place we need a theory of meaning-making that accomplishes two important objectives. First, it must be able to account for somatic experience as well as symbolic experience. Second, it must also account for the relationship between mental and cultural models; models in our minds and in the world.

There are two theories that I believe accomplish the above goals. Conveniently, they are so similar that they can easily be considered as a single theory. The concept of *sense-making* used by the design theorist Klaus Krippendorff (Krippendorff, 2003) is one, and the notion of *meaning construction* used by cognitive anthropologist Bradd Shore (Shore, 1996) is the other. Both of these describe the process of design, of synthesizing new artifacts in the material world, as well as the process of experiencing existing artifacts and comprehending their meanings. Shore connotes these dual aspects of meaning construction using the separate, but related, concepts of *externalization* and *internalization*. These terms denote the way mental models are transformed into cultural models and how cultural models are transformed into mental models, respectively. I address Shore's ideas of internalization and externalization in regard to understanding the campus tour in the context of the "walkabout" model in Appendix XX. At this time I would like to address the ideas of Krippendorff, who summarizes them this way in the context of the phrase "design is making sense (of things):"

> The phrase is conveniently ambiguous. It could be read as "design is a sense creating activity" that can claim perception, experience, and perhaps esthetics as its fundamental concern and this idea is quite intentional. Or it can be regarded as meaning that "the products of design are to be understandable or meaningful to someone" and that this interpretation is even more desirable.
>
> (Krippendorff, 2003, p. 156)

However cryptic Krippendorff's statement might be, it contains the essential element that design has at its core some notion of "sensation." That is, it appeals to the senses and direct physical experience. Whether these belong to the end-user or the designer is left intentionally ambiguous because sense-*making* an artifact (design) and making-*sense* of that artifact (use) are mirror images of the same processes.[4] Sense-making calls upon the senses and sensibilities of the designer to construct an artifact, and making sense of that artifact requires that the consumer engage with it using their own senses. This view apparently emphasizes the lower-level sensory-motor aspects of sense-making, but also, as both Shore and Krippendorff acknowledge, requires some other higher-order, indirect, and symbolic cognitive work as well. In this way, it refers to a higher-order "sense" of something the way one has a "sense of self" or perhaps even a "sense of humor about one's self," and, importantly, a "sense of place." Krippendorff again:

> However, making sense always entails a bit of a paradox between the aim of making something new and different from what was there before, and the desire to have it make sense, to be recognizable and understandable. The former calls for innovation, while the latter calls for the reproduction of historical continuities. In the past, sense was provided by alchemy, mythology, and theology. Now we speak less globally of a symbolic ordering that is constitutive of cognition, culture, and reality.
>
> (Krippendorff, 2003, p.156)

Clearly there is more to sense-making than can be supplied by the sensory-motor apparatus, and Krippendorff locates these symbolic components of sense-making at the intersection of "cognition, culture, and reality." It is not much of a stretch to include mixed reality as a subset of reality, and so, as this work is also situated at the intersection of these three domains, it makes sense to employ sense-making as our model of choice for understanding the interaction of these elements.

One additional point in favor of Krippendorff's notion of sense-making is that he also offers something closer to a low-level cognitive process model of how it might operate:

> Making sense is a circular cognitive process that may start with some initially incomprehensible sensation, which then proceeds to imagining hypothetical contexts for it and goes around in a hermeneutic circle during which features are distinguished—in both contexts and what is to be made sense of—and meanings are constructed until this process has converged to a sufficiently coherent understanding.

[4] I will use "sense-making" to refer to both.

(Krippendorff, 2003, p. 160)

Obviously, this model isn't at the level that a computational neuroscientist or roboticist would be happy with, as it doesn't really have much by way of implementation details. Still, this kind of convergence is known to occur in networks, neuronal or otherwise, and is often referred to as an "attractor network" (Kelso, 1995). Additionally, the notion of convergence is essential to many machine learning algorithms, and so is at least a superficially valid model.

The mechanics of sense-making posited by Krippendorff have a number of useful components. For one, the idea of a circular repetition of feature extraction is very much akin to loop, something both humans and machines do rather nicely. However, this loop isn't infinite, it is in fact less circular and more spiral, and terminates at a point of *convergence*, or what systems scientists refer to as *stability* (Kelso, 1995), between representations of direct physical sensation and imagined, or symbolic contexts. As a cyberneticist, as well as a design theorist, Krippendorff is no doubt aware of the importance of convergence to social and cognitive networks, and this must naturally have informed his description. Shore posits a similar mechanism using the notion of *analogical schematization*, essentially a metaphorical mapping between sensorimotor and symbolic processes, an idea also implied in the earlier work on embodied cognition. Tuan also has similar feelings about place; defining it alternately as *pause, permanence,* and with the following passages:

> Place is an organized world of meaning. It is essentially a static concept. If we see the world as process, constantly changing, we should not be able to develop any sense of place. Movement in space can be in one direction or circular, implying repetition.
>
> (Tuan, 1977, p. 179)

> Place can be defined in a variety of ways. Among them is this: place is whatever stable object catches our attention.
>
> (Tuan, 1977, p. 161)

I mention this notion of convergence as a model of sense-making not because I intend to investigate it directly, either in the brains of subjects or as a runnable computational process, but for more pertinent reasons. First, convergence has also been observed in various MR experiences (Benford and Giannachi, 2011), and I will delve into this point further in a moment. More pertinently though, the ideas of circularity, repetition, and convergence to a stable state can help us draw one final connection that will aid in understanding scale as a basis for a language of MR.

Concepts of space and place are also of great importance as theoretical and practical concepts in architecture. Of particular interest are the notions of *design patterns* and *pattern languages* developed by Alexander (Alexander, 1979, Alexander et al., 1974). Alexander's work echoes a number of the sentiments expressed about space and place already. The motivation behind the idea of design patterns, which are essentially templates for solving recurring problems in architecture and urban planning, is Alexander's belief that successful building requires creating the necessary conditions that produce "the quality without a name." Although this esoteric construct borders on the mystical, and Alexander at times seems to imbue it with mythical significance, he is also quite adamant that it is something we can grasp and achieve in our design of the built environment. In his attempts to explain it, he uses a variety of language that should be quite familiar by this point:

> The quality without a name is circular: it exists in us, when it exists in our buildings; and it only exists in our buildings, when we have it in ourselves.
>
> (Alexander 1979, p. 62)

> Places which have this quality, invite this quality to come to life in us. And when we have this quality in us, we tend to make it come to life in towns and buildings which we help to build. It is a self-supporting, self-maintaining, generating quality.
>
> (Alexander 1979, p.53-54)

The first of Alexander's sentiments echoes the ideas of internalization and externalization discussed above in regard to the sense-making process, while the second hints at the idea of convergence in sense-making. However, Alexander doesn't stop there. Despite the fact that the quality with no name has no name, he nonetheless uses a number of words to try and make sense of it, in a fittingly circular fashion:

> I shall try to show you now, why words can never capture it, by circling round it, through the medium of a half dozen words.
>
> (Alexander 1979, p. 29)

The words Alexander uses: *alive, whole, comfortable, free, exact, egoless, eternal*; all invariably fall short in his estimation, and so he falls back on one final word:

> In short, saying that these patterns are alive is more or less the same as saying that they are *stable.*
>
> (Alexander 1979, p. 118)

> If the patterns out of which a thing is made are alive, then we shall see them over and over again, just because they make sense.
>
> (Alexander 1979 p. 149)

The patterns that Alexander concerns himself with are not only patterns of space. It is more accurate to say that he is interested in the way patterns of space can be related to the patterns of events that repeat in that space and, like Tuan, our experience of them.

> Those of us who are concerned with buildings tend to forget too easily that all the life and soul of a place, all of our experiences there, depend not simply on the physical environment, but on the patterns of events which we experience there.
>
> (Alexander 1979, p. 62)

Tuan makes a similar point, quoting the philosopher, Susanne Langer:

> As Langer put it, "The architect creates a culture's image: a physically present human environment that expresses the characteristic rhythmic functional patterns which constitute a culture." The patterns are the movements of personal and social life.
>
> (Tuan, p. 164)

The connection between patterns in space and patterns of events is also essential for capturing and representing cultural heritage. One might conceive of cultural heritage explicitly as the patterns of "personal and social life," which correspond to the notion of *intangible* cultural heritage. More traditionally though, cultural heritage has been defined in regard to objects, buildings, or other sites of *tangible* or physical cultural heritage. Both meanings are in play here. The notion of cultural models being externalized in artifacts and what Tuan refers to above as the "public and material reification" of mental processes in "tangible material" resulting in, "sculptural and architectural space," is an important connection.

It is this last phrase of Tuan's that I believe holds the key to new way of thinking about MR experiences. The idea that we can find culture, and place, in material objects like monuments and sculptures, larger spaces like buildings, and even the "large-scale" city is indicative of a way of thinking about space and place that operates on *multiple scales*. Kernels of this idea can be seen in the writing of both Shore and Krippendorff. Indeed, the very notion that meaning is constructed from lower-level sense impressions and higher-order symbolic processes is itself based on some notion of scale. However, in Alexander's work this idea is fundamental to the way that design patterns are connected into a *pattern language*.

For Alexander, design patterns can be defined at multiple scales. They describe the arrangements of objects in the space of a room, they describe the way that room is situated in relation to other rooms of a building, they describe the way groups of buildings form a neighborhood, etc., on up to the level of entire regions or nations. He also states this explicitly:

> Patterns can exist at all scales.
>
> (Alexander 1979, p. 247)

Tuan makes a similar statement in regard to place:

> Place exists at different scales.
>
> (Tuan, 1977, p. 149)

The relationships between patterns at any given scale to the patterns above and below it are what define a pattern language. Am I suggesting that a pattern language can be made for MR the way that Alexander et al. have made one for the built environment? Yes, I believe that is possible, and some work I have been involved with has already gone down this path and been well-received (Xu et al., 2011). Unfortunately, MR, unlike architecture, is still only in its adolescence, and there is much more growth needed before we can articulate a clear pattern language. However, as a starting point, we must recognize that any pattern language will necessarily involve the integration of design patterns at multiple scales. So, as a step toward the ultimate goal of creating a pattern language for MR, I offer the MRSF, already shown to be a valuable tool for understanding space at multiple scales in MR experiences.

5.2 The Language of MR

"The most natural cut is the cut on the look."
-Jean-Luc Godard

In order to answer the question of how to build a pattern language for space and place based on the scales of the MRSF we need to understand something about how languages in other media are constructed, and how we make sense of them. While it is likely a cliché in film studies to quote from Jean-Luc Godard, it is still relatively rare to do so in fields relating to computing. Yet, there is much packed into this short statement by the master filmmaker that can show us the way toward developing a language of MR. There are three points to note about Godard's statement, however, I should say at this point that the following discussion should be specifically taken in the context of "continutity-style" film editing. This is the style used in the "Hollywood" films that we are most familiar with, but is more generally the style of most "narrative" films. Other styles are also prevalent and make meaning differently. Often, this meaning derives from the fact that such films "violate" the continuity style, yet alternatives to continuity filmmaking should still be acknowledge. The reason for focusing on the continuity style in addition to its prevalence, is that it offers s direct correlate to the notion of continuity that I have been developing throughout this work as a means of understanding MR experiences. This connection is an obvious one and will help to identify lower-level correlates upon which to base a language of MR.

The first point to note about Goddard's statement is its subject: "the cut." The cut is the most fundamental building block of film editing, and essential to the "language of film," particularly in regard to the continuity style. It is through the skillful use of cuts and a handful of other techniques, that filmmakers can control the perception of space in a film, control the pace of the narrative, and even reveal the internal minds of the characters to create drama and tension. As I said though, the cut is just a foundational building block, it must be taken in context with what comes before and after it. Cuts might be considered the punctuation marks of the film language, on there own they convey very little. In order to be meaningful they must be combined with shots, and built into sequences and scenes, the way that words are built into sentences, paragraphs, and dissertation chapters. What's more, cuts and many other elements of film language are often imperceptible to spectators, just as scales are imperceptible to MR users.

The second concept we can infer from Godard's statement is that cuts and other film techniques can in some way be "natural," a somewhat perplexing notion for a medium as artificially constructed as film. Still, most of us would agree that some cuts are jarring and others are seamless. The question of what is or is not natural about how various media artifacts make meaning is an integral question in media studies and one that is often punted on by theorists because it is most likely inherently unanswerable. The relationship between natural experience and cultural convention is in my estimation, a cognitive one; a form of the nature-nurture debate. This debate takes shape in film studies as the "realist" (Bazin, 2004) and "formalist" (Bordwell and Thompson, 2004) approaches to film criticism. On the one hand, the realist interpretation emphasizes film's ability to reconstruct the spaces and actions of our everyday experience as the basis for our ability to make sense of the artificially constructed times and spaces found in film. On the other hand, the formalist approach posits the techniques used to structure the various elements of a film as the primary mechanism of meaning construction. I see no need to add anything to this continued and often heated debate in the film theory community, nor do I wish to take one side or the other. Instead, through an articulation of both mind and culture as a collection of models derived from both *direct* physical experience and *indirect* symbolic thinking I hope that I have shown that we can understand the relationship between media artifacts and natural experience as continuous loop of *sense-making* in which these models are being *internalized* in the minds of individuals and *externalized* in the artifacts we produce, films being one example.

The final point to make in deconstructing Godard's statement regards the thing he considers to constitute a natural point of intervention for film editing: "the look." It is not surprising that Godard emphasizes this aspect of editing, rather than motion or dialog, which are perhaps equally natural and represented in film. In contrast to MR, film is a primarily visual medium and references to editing often demonstrate this bias (Murch, 2001). Looking requires both a physical body with which to look and a motivation for looking that is inherently cognitive, and often social. Looking around then can be understood as a kind of physically embodied editing practice. Turning one's head to face a co-worker when they call your name, looking at a door when someone enters a room, even just looking away from your computer screen to rest your eyes, are all ways that we visually "edit" our immediate perception of space in the natural course of our experience, and each of these has its own motivations. Our implicit, personal, and embodied knowledge of these motivations are what help us decipher the language of film editing, and the changes in viewpoint that looking accomplishes correlate well to the changes in viewpoints achieved by different camera angles, positions, and movements. I suggest a similar approach to understanding the experience of MR. However, where film is a voyeuristic medium with looking as its primary means of identification, MR is a primarily experiential medium where *participation* is the key element. That is not to say that looking isn't important–it is. In the same way movement and hearing are important in film, and one can become immersed in a story. Yet, physical participation is added to these in MR, in a way that cannot be found in other media.

5.2.1 Building Patterns from Pieces

Many filmmakers continue to advance the techniques of cutting film. However, the techniques themselves are simply words, punctuation, or at best short sentences in the language of film. It is through their repeated assembly into larger elements that they gain new significance as conventional patterns and serve as models for future filmmakers. Although, the connection between the development of media conventions associated with film language, and Alexander's notions *design patterns* and *pattern languages,* has gone largely overlooked in the scholarship in both domains, the connection is fairly obvious. Lev Manovich makes this connection implicitly when he defines exactly what he means by the use of the term "language" in the title of his book, *The Language of New Media* (Manovich, 2002), saying:

> "...it was important for me to use the word *language* (sic) to signal the different focus of this work: the emergent conventions, recurrent design patterns, and key forms of new media."
>
> (Manovich, 2002)

I would add to this definition that the word language also implies both a connection to the human mind and a cultural connection through symbolic encoding. This is the sense in which I use the term language to describe a language of MR.

Design patterns were put forth as a means to consolidate and communicate solutions to common problems in architecture and urban planning and, as Alexander et al. describe, combine to form a generative pattern language. They say:

> The elements of this language are entities called patterns. Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice.
>
> (Alexander et al, 1977 p. X)

This basic description, written to explain the use of architectural design patterns might just as easily describe a formal convention in filmmaking, or an element of the language of new media discussed by Manovich. One example of this might be found in the number of possible design patterns that emerge from the 180-degree rule in filmmaking.

The "shot-reverse-shot" (SRS) pattern is one convention for constructing filmic space often talked about in relation to the "180-degree rule" or the "line-of-action," and is an excellent example of a design pattern in film that fits the above definition. The 180-degree Rule is depicted in below and is defined as the imaginary line made by the line-of-sight of two actors in a scene:

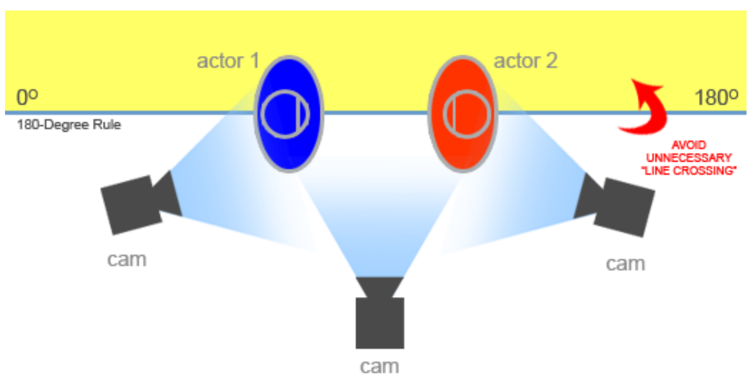

Figure 6.1. 180 Degree Rule

One aspect of the 180-degree rule and the patterns derived from it, like SRS, is that there are any number of ways to observe these rules, "without ever doing it the same way twice," as Alexander et al. suggest regarding design patterns in general. Placing a camera anywhere on the correct side of the line for a SRS pattern is perfectly acceptable and as Fairservice says:

> "…provided the camera always remained on the same side of the action, the spectator would accept the construction as logical and realistic."
>
> (Fairservice, 2002 p. 105)

Furthermore, in language that echoes Alexander's definition of a design pattern as describing the core of a solution to a recurring problem, he claims that,

> "It [SRS] was developed in an attempt to resolve the problem of showing action in different parts of a scene when the logical assumption was that a spectator can only observe action occurring in any given scene from one fixed position."
>
> (Fairservice, 2002 p. 84)

For Manovich, the lineage from cinema techniques to those found in new media is a clear one, and film serves as his basis for the language of new media. While not explicitly called by name, MR has what Manovich considers to be the five characteristics of new media: numerical representation, modularity, automation, variability, and transcoding. While all of these could be examined in detail, I want to focus for now on the notion of *modularity*, as this quality is closely tied to the notion of scale.

5.2.2 The Multiscale Structure of New Media

Manovich summarizes the quality of modularity by as "the fractal structure of new media," which he describes in the following way:

> Just as a fractal has the same structure on different scales, a new media object has the same modular structure throughout. Media elements, be they images, sounds, shapes or behaviors are represented as collections of discrete samples (pixels, polygons, voxels, characters, scripts). These elements are assembled into larger-scale objects but continue to maintain their separate identities. The objects themselves can be combined into even larger objects — again without losing their independence.
>
> (Manovich 2002, p. 30)

What Manovich is describing here is what I would refer to as the *multiscale* structure of new media. Alexander describes a similar multiscale structure, and I have offered one for MR in this dissertation, suggesting that the language of MR must ultimately take the form of a pattern language.

For Manovich, the five characteristics of new media all have their roots in the industrialization of society and are intimately connected to the culture that arose during that historical period. Manovich argues however that "…new media follows, or actually runs ahead of, a quite different logic of post-industrial society—that of individual customization, rather than mass standardization." Yet, the notion of modularity, a key element of new media in Manovich's conception, is clearly still mired in the industrial model of factory production. Rather than being a criticism of Manovich's logic, this apparent contradiction serves to illustrate that new media, like older media, owe much of their forms, their meanings, their language, to those that came before them. Again, this is very much in line with the argument of this work: that the meanings we find in technologically enabled media are the result of an interplay and coevolution between our natural experience of our bodies (particularly in space) and our experience with the methods used to encode that experience in symbols.

Shore also examines the notion of modularity, and draws many of the same conclusions that Manovich does. However Shore's focus is not on media specifically, but rather on the relationship between the cultural and cognitive models that shape our interpretations of everyday life. As such, Shore's analysis adds an interesting cognitive component to our analysis of new media. Shore introduces what he calls the *modularity schema* as follows:

> This modularity schema, through its power to structure a very large number of specific cultural models, virtually defines the cognitive landscape of modernity and has a lot to do with the emergence of a recognizably postmodern mentality. What I call the modularity schema is also understandable as a kind of high-tech cognitive style, a machine-driven logic that has powerfully affected the way in which much of our knowledge of the world has been coded.
>
> (Shore 1996, p.117)

Shore's observation that modularity is a defining category of modernity, and one of the underpinnings of the postmodern mentality that follows it, also situates modularity in a post-industrial framework, and squares nicely with Manovich's notion of the standardization and division of labor that characterized media production and cultural life in the early 20th century. Furthermore, Shore's assertion that continued exposure to the modularity schema, in the form of artifacts and processes, during the modern era was essential to the emergence of a "postmodern mentality" goes a long way toward explaining why modularity is a key element of new media artifacts. However, it does not get us all the way there because modularity is also intrinsic to how the computer is organized and operates at its most basic levels, and so is not solely a category of human thinking. Yet, the extent to which this essential design of the computer might also be an artifact of modular thinking is an interesting question. It seems that there is a kind of bootstrapped chicken or egg problem in which modular thinking is continuously being encoded into artifacts and processes like computer code, assembly lines, and new media objects, and that these modular artifacts influence the way we, as consumers and producers of technologies, think about and structure our experience of the world. This mode of thinking then becomes re-represented in new artifacts that further influence thinking, and the process continues. These are the twin process of internalization and externalization that form the basis of sense-making as I have outlined in the previous chapters.

5.2.3 Convergence

I have already discussed the notion that design patterns describe the connection between events and the spaces in which those events take place and, by extension, pattern languages connect these design patterns across scales. I also noted that the connections between lower-level patterns and higher level patterns are a key element of multiscale design and that this idea is described in the literature on game design (Björk and Holopainen, 2004) and systems science (Bar-yam, 2005) as *emergent* behavior. In both these conceptions the idea of *stability* is central. Alexander et al. consider a pattern to be functional when it reliably creates stable patterns of events, and Krippendorff, describes the cognitive process of sense-making as the stable convergence of sense impressions. Taken together, this related work suggests that a stable pattern of events in physical space (interactions) could potentially create a stable pattern of symbolic interpretations as well.

The notion that a pattern of physical interaction can create emergent conceptual structures, despite being theoretically defined, is a difficult notion to demonstrate empirically or design for in the field. Yet, as I mentioned in the discussion of [inbox], this is exactly what designers of multiscale MR experiences must attempt to accomplish, as emergent concepts are integral to how participants create meaning during multiscale MR experiences. In an ideal design of a multiscale MR system the topmost global elements that frame the experience should "trickle-down" to interactions at lower scales, constraining more detailed and specific interactions and privileging specific meanings. As users interact at these lower scales, they will be accessing these implied meanings, and building a "bottom-up" mental model of the whole experience. If designers do their job well, their top-down mental model externalized in interactions and artifacts, and the bottom-up internalization of these interactions should converge on a single meaning, that is, communicate a single mental model. This is a simplistic and ideal scenario, and there are many subtleties that have the potential to confound this situation. Yet, if creating a meaningful connection is our goal, the convergence of top-down and bottom-up meanings is something that needs to be explicitly designed for, and we need constructs and metrics that we can use to evaluate our success in this process. I suggest that *canonical* and *participant* trajectories, discussed below, are potential constructs for understanding the communication of meaning in MR experiences.

5.2.4 Meaning and Identity as the Resolution of Tension

Ritual has traditionally been the focus of anthropological studies, but has also been used by games researchers and, more recently, video game researchers. For example, Huizinga's seminal work on play (Huizinga, 2003) defined the spatial and mystical concept of the "magic circle" of game players that marks the boundaries of play;

a distinction taken up by many games researchers, such as McGonigal (McGonigal, 2003, Mcgonigal, 2006) and Salen & Zimmerman (Salen and Zimmerman, 2003). The work of Victor Turner (Turner, 1995) on "liminality" in ritual also crosses into much of this territory, and bridges a divide between games studies, performance studies, and anthropology. Liminality is directly related to the process of identity-formation and is understood as a transitional state that occurs in a ritual when a participant sheds the identity they had before the ritual began, but has not yet adopted the identity that they will have when the ritual completes.

Ritual practices do the important work of ensuring that individuals who engage in them form what Shore refers to as *conventional mental models*, mental models held commonly by members of a social group and that this is their initiation into culture. In Appendix X I discuss how rituals also allow for the individual to schematize their own *personal mental models* of these experiences and so are open for interpretation. The idea that personal and conventional mental models exist in a kind of tension is a key element of identity formation, particularly during the liminal stage of ritual practices, Shore, Goffman, and Turner all agree on this point. The resolution of tension is also considered a key element of narrative in many conceptions, dating back to Aristotle (Aristotle, 1996). In all these various conceptions, Tension must proceed to resolution, and we can also understand resolution as convergence to a stable meaning. Convergence is largely how meaning is constructed in both the model view espoused by Shore, and the trajectories view as well. Achieving convergence between personal models and conventional models is how Shore conceives of identity formation, and what he considers to be the point of rituals like the walkabout also discussed in Appendix X, which I also suggest as a model for understanding MR walking tours.

Benford & Giannachi (Benford and Giannachi, 2011) also discuss the process of convergence, and its counterpart, *divergence* as forces that affect the overall trajectory of a MR experience:

> This tension between the continual divergence and reconvergence of canonical and participant trajectories is a productive one, providing that they are kept in balance. Too much divergence and the experience may fall into incoherence and the underlying narrative will disappear. Too much convergence and the interactivity is lost. Divergence and convergence are driven by two opposing forces. Interactivity is the force that drives divergence [corrected from original text], pushing canonical and participant trajectories apart, and orchestration is the opposing force that drives reconvergence, steering them back together.
>
> (Benford and Giannchi, 2011, p. 236)

Although, the notions of convergence and divergence discussed here seem to refer more to the physical or spatial qualities of the trajectories, we must also assume that physical trajectories are accompanied by cognitive trajectories as well, making them both somatic and symbolic. This is a natural result of "experiencing" different things; different physical experiences result in different mental experiences, and similar physical experiences result in similar mental experiences across individuals, with variation across cultures.

The potential cognitive correlates of physical trajectories very closely match the notion of mental models I have been using, and this can be seen in Benford & Giannachi's characterization of the forces that shape convergence and divergence. The force that shapes convergence, orchestration is the result of careful planning and constant real-time adaptation. Interactivity, the result of personal choice causes divergence between trajectories. These ideas correlate to the notions of personal and conventional mental models. Conventional mental models can be associated with notions of convergence. In the case of walking tours, and seemingly in other ritual forms, they are the product of orchestration, and keep the experience "coherent" or "stable" among different individuals, and keep the "underlying narrative" built into the experience intact. Personal mental models are considerably more varied. They are the products of interaction, but personal mental models are also a direct result of personal reflection and individual identity. The productive tension between personal and conventional mental models that results in individual identity formation, is very much the same tension between convergence and divergence that Benford & Giannachi believe is integral to a balanced MR performance. In fact, too much divergence between a canonical and participant trajectory could be said to result in a participant trajectory, an "identity" within this semantic system, which is simply not reconcilable with the canonical trajectory. The point here is that the resolution of tension through convergence to a stable mental model is itself a cognitive model of meaning construction. This process is integral to the participatory experience of MR, as well as the continuity style of filmmaking. In filmmaking tension is created and resolved by creating continuity across moving images, largely through the use of cuts. My argument is that in MR a similar continuity is achieved through the use of scale transitions.

5.3 The Language of MR in the Continuity Style

Through this chapter I have drawn a number of connections between notions of place and space essential to understanding the experience of MR, the idea of convergence between mental and cultural models that exist in the world and in our heads, and the importance of design patterns in achieving continuity in film and in the human experience of space. While I would sincerely have loved to draw some firm conclusions and outline a language of MR, I do not believe that this is warranted at this point. Instead, I hope that this exploration of the fundamental connections and similarities between concepts common to the transformation of space into place and the established continuity-style of filmmaking are compelling enough to invite further exploration and discussion.

CHAPTER 6

CONCLUSIONS

6.1 Summary and Conclusions

In Chapter 1 I laid out several research questions and hypotheses about the role of spatial scale in MR experiences. In the ensuing chapters I detailed a number of studies designed to answer those questions and provided evidence resulting from those studies that support the stated hypotheses. In this chapter I will revisit those original questions and hypotheses and use the knowledge that was gained from those studies to draw a number of conclusions and offer new questions that this research suggests should be pursued in future work.

6.1.1 Hypothesis Set 1

The first set of hypotheses and research questions were intended to elucidate the role of spatial scale in MR experiences, in terms of their structure and effects on user behavior.

> Hypothesis1. Existing MR experiences can be analyzed in terms of their use of spatial scale to account for observed behaviors and to isolate new constructs for future consideration in design and analysis that are not accounted for by current approaches.
>
> Question1. What new insights can be gained from examining MR experiences from the perspective of spatial scale that could be applied to future design or analysis?

In an attempt to answer this first question and support this first hypothesis I began with the study of [inbox]. I was able to demonstrate through participant-observation and post-experience interviews that some users of [inbox] had a number of issues trying to find "meaning" in the experience. While users' were commonly able to derive some meaning from interactions at each of the 3 distinct "stations" that constituted [inbox], they also had the expectation that these individual interactions should have been "coordinated" in such a way that they maintained a *continuity* across the entire experience. Rather than communicating separate ideas or concepts, these interactions should have connected to each other in a way that provided for connections between each of the stations to be more palpable.

The idea of preserving continuity across scales became a sensitizing concept for further investigations, and, when applied to the BeeHive study, resulted in the notion that *coordination of representations between scales* is a fundamental concept in effective multiscale MR design. By re-analyzing the BeeHive study from the perspective that "placemaking" is a failure of technological transparency I was able to show that this failure due to the system's lack of provisions for the coordination of representations between scales. I further suggested two possible alternatives to the MapLens system that could have potentially mitigated this problem. The first was *offloaded coordination* in which the technology removes the need for users to actively coordinate representations. The example of this was a "heads up" arrow that a user can follow through the environment, and which was incorporated into the design of the MR walking tour. The second suggestion was the ability to select a landmark on the map and have it highlighted when the user views the surrounding panoramic space with their device. A third strategy would be the inverse of this, in which markers in the surrounding environment could be scanned with a device to activate a highlighted location when the map is viewed.

In both the [inbox] and BeeHive studies the behaviors of users can be adequately described in terms of their thinking and reasoning around spatial scale. Doing so provided new insights about how problems with the design of these systems resulted in the observed behaviors, and in both cases thinking in terms of spatial scale was able to suggest different strategies that might lead to more effective designs. The concept of the coordination of representations across scales was identified as the major impediment to effective use and understanding of both those systems, a construct not accounted for in existing MR frameworks.

6.1.2 Hypothesis Set 2

> <u>Hypothesis2</u>. Designers of MR experiences intuitively make use of spatial scale. When we examine the thinking involved in the MR design process, we can identify the role of spatial scale and extract concepts and strategies that might facilitate the design process.
>
> <u>Questions2</u>. How does spatial scale influence the thinking of MR designers? Does identifying this influence offer strategies that could aid the design process?

The second set of hypotheses and questions is aimed at elucidating the role of spatial scale in the cognitive processes of designers, in the hopes that this analysis will reveal how we might aid or improve this process. There are really two hypotheses here and the second follows naturally from the first. Although there is evidence to support the argument that spatial scale is fundamental to the human experience of space (see Chapter 2) it is not known and has not been shown that scale influences the thinking of MR designers and users. One would expect that if scale were indeed fundamental to human spatial cognition, than it would appear in a number of places in regard to MR, which is inherently spatial. One area, as discussed above is in the thinking, and particularly the expectations of users of MR systems. In addition to the evidence cited above, additional support for this can be found in the user study of the GTour application in Chapter 4 and discussed further below.

Another place we would expect to see scale thinking is in regard to analysis of MR systems, and I demonstrated how scale-thinking accounts for differences in focus among a number of different conceptions of MR in Chapter 2. While all those conceptions describe the use of technology to mediate the human experience of space, the approaches favored by Milgram & Kishino, Azuma, and others emphasize visual mediation, which is common to the panoramic and figural scales. McGonigal and others in the HCI and games communities focus much more on the conceptual mixing of realities and this locates their approach at the global and environmental scales. I concluded that Chapter with a more all-encompassing definition of MR that was derived by connecting those differing notions together through the concepts of embodied cognition and conceptual framing, found in the work of Lakoff & Johnson, Goffman, Turner and others. As more evidence of scale-thinking in MR research, I re-analyzed the work of Benford et al. in terms of scale and determined that the categories they used differentiate MR systems along the "spatiality continuum," topology, orientation, movement, and place all corresponded to the different scales of the MRSF, demonstrating the implicit role of spatial scale in their reasoning.

The last area where we should find evidence of scale-thinking in MR is in the reasoning and creative processes of MR designers themselves. We might expect that scale-thinking should appear in both the products of this process, and in the processes that those products result from. Initial support for this hypothesis was found in refection on the design process of [inbox]. Each of the stations that comprised [inbox], the map, the desk, and the slideshow, were all unconsciously designed to take advantage of embodied interactions at the environmental, figural, and panoramic scales, respectively. However, because this thinking was unconscious and unintentional we were unable to fully take advantage of all the affordances of scale. Reasoning from this conclusion, I suggested a number of alternative techniques that we might have used to better communicate with participants by drawing on their innate understanding of scale if it had more explicitly informed our design of the [inbox] experience.

The most convincing evidence for the role of scale in MR design, which also supports the second hypothesis that we can extract useful new strategies and concepts to inform future design came from the interview study in Chapter 3. In that study I showed that Subject #1 used scale to make an analogy during the inception phase of his project. He wanted to make an application to aid in the end-user assembly of furniture from printed instructions. His approach for this figural scale MR experience came from reflection on his own preference for navigation: to use the directional pointing and visual search instead of sequential instructions. While he never reached the stage of actually developing an application he was nonetheless drawing on his innate understanding of space and scale.

Subject #2 was only slightly more successful in his attempt to build an MR experience. His attempts to reproduce the environment of artist Howard Finster's Paradise Garden in MR had to be scaled back to a collection of panoramic spaces. While this approach did help visualize a number of Finster's artworks in their original context, these were disjointed and failed to recreate the experience of being at Paradise Garden. However, although subject #2's efforts were thwarted by logistical and technical details, his reasoned belief that he could approximate the Paradise Garden environment with a succession of panoramic spaces was fundamentally correct, and suggested that the technique of *environmental approximation* demonstrated by subject #3 and in the GTour application is an intuitive design approach rooted in scale-thinking.

Subject #3 had the most success in his implementations of MR experiences, and also has the most to offer in terms of his use of spatial scale. As mentioned above his successful execution of what he referred to as a "panorama grid" gave users of his Walking Dead TV Companion the ability to experience the mixed reality of downtown Atlanta and TV's Walking Dead and demonstrated the value of *environmental approximation* using a collection of panoramas. Furthermore, his belief that collections of panoramas separated by distances further than the eye could see required exiting to an environmental view (map) to establish a conceptual connection between them, suggested the design principle that panoramic spaces are bounded by line of sight. An accidental violation of this principle resulted in confusion during the GTour user study, further suggesting its validity. The clearest evidence of scale-thinking in subject #3's design process though came from his insightful implementation of a class of interactive techniques that I have dubbed *scale transitions.* In his bus-finding application subject #3 introduced an embodied transition for moving between the figural scale of the map, and the panoramic space of the surrounding environment. When the user lays the device flat, the map animates into view, and when the user raises the device vertically, it slides away, revealing an arrow that points to the nearest bus stop. These examples demonstrate that problems surrounding the coordination of representations between scales are quite common in the design process, and the creativity of MR designers in solving these processes requires accessing innate understandings of spatial scale. The resulting solutions are potentially useful techniques and strategies that can be employed in a number of different scenarios, and represent the beginning of a collection of interactive techniques for multiscale MR design that have the potential of aiding future designers faced with similar problems.

6.1.3 Hypothesis Set 3

The third hypothesis and question set specifically addresses the use of spatial scale in the design, implementation, and evaluation of the campus tour experience.

> Hypothesis3. Applying a multiscale framework to the analog campus walking tour will result in new knowledge that can be transferred to a MR campus tour by locating opportunities for design intervention, providing explanations of encountered design problems, suggesting solutions to those problems, and describing observed user behaviors.
>
> Questions3. What is the role of scale in the analog campus tour? How could a MR version of this tour use scale more productively? How does spatial scale inform the construction of the MR tour and influence the experience of participants?

The essence of this hypothesis is that sensitivity to spatial scale and use of MRSF during every stage of the design process yields a coherent understanding across all of these that results in a usable application, if not an improved one. During the initial requirements gathering I observed a number of tour groups, information sessions, and analyzed the campus tourism web portal to understand the way information was being communicated during the campus visit process. I found the use of mental and cultural models to be an effective means of understanding the structure and purpose of the campus visit experience, and the particular model of the “walkabout” helped to explain the cognitive processes and ritualistic underpinnings of the campus tour. With mental and cultural models as constructs upon which to base an analysis of scale I was able to determine the role of the information session in the campus visit as an attempt to bridge the gap between the conventional mental models of campus visitors and the instituted models of Georgia Tech. This made the information session a kind of scale transition between the global and local scales, however, because the campus walking tour was not geared to individual interests, personal mental models specifically, the opportunity to frame the experience in ways that would be most personally meaningful for participants was lost. This was an opportunity for design that was incorporated into the MR version of the tour through selectable tour routes and curatorial control over information.

Observations of the walking tour itself, through the lens of the MRSF, also yielded important concepts and identified opportunities for design. The most generally applicable concept derived from observation of the campus walking tour was the notion of *scale matching* in which the information being delivered is relevant to the scale at which it is delivered. Scale matching was the principle by which information was delivered by tour guides during the long walking portions of the tour. Locomotion is indicative of the environmental scale and during these walking periods the information delivered through stories and facts was about the more general aspects of Georgia Tech. These included notable alumni, student life, different majors, study abroad and internship opportunities, etc. When tours reached pre-determined "stop-and-talk" points, which were panoramic spaces, the information being delivered also matched this scale. Information of this type focused on the buildings themselves (when they were built, the departments housed there, etc.) and features of the immediate environment (emergency call boxes, shuttle-bus stops, etc.). The implications of scale matching for the MR walking tour came in the form of delivering information at the environmental scale, while walking the tour route and following the directional arrow. Although audio functionality had not been implemented for technical and logistical reasons, placeholders were created for this content to be added at a future date. The purpose of such audio would be as a replacement for the physical tour guide, delivering environmental scale information filtered by the interests of the individual participant. Because this information is about the more general environment it is most appropriate to deliver it during locomotion. Furthermore, the presumption that audio-content of this type would need to be tailored to the immediate environment in order to make sense to participants, for example, "You are walking past the only working steam whistle in the city of Atlanta," seems not to be the case. This point liberates the tour creator from needing to create content for specific routes, and suggests that including content relevant to the interests of the participant rather than information more closely tied to the surroundings is perfectly acceptable.

A final insight gained from scale analysis of the walking tour surrounds the use of figural scale materials during the tour experience. The only figural scale materials available to participants were written materials on topics of general interest. These included the same types of information delivered by tour guides: study abroad, majors, clubs, sporting events, facilities, etc. Tour participants would often read these materials while walking, requiring them to split their attention and then re-focus when the tour reached a "stop-and-talk" point. This was an opportunity for design exploited in the MR walking tour, which more closely bound figural scale materials to the surrounding panoramic space to maintain the hierarchy of scales and keep figural scale materials contextually relevant.

I have also argued that the scale played an integral role in the system implementation of the MR tour. To begin, a number of observations and insights that were reiterated above as findings from the observational study of analog tour participants became design principles for the MR implementation. For one, while the initial campus visit website and information sessions that precede the campus walking tour make considerable efforts to appropriately frame the participants' experience in terms that speak directly to their mental models, the physical tour itself fails to continue in this vein.

While some tour guides make an effort to personalize their tours to the individuals on it, the route is always the same, and topics never stray too far from the script. The MR version seizes this opportunity to frame tour experiences at the global scale through the construction of multiple tour routes. This feature allows participants to select the tour that best matches their personal interests, and even jump between tours that represent different interests. This aspect of tour-taking is also embodied in the role of the tour designer who has the ability to cherry-pick information at every scale to provide a unique and thematically consistent tour experience coordinated at multiple scales.

A second design opportunity identified in the analog tour involved the use of figural scale materials. In the analog tour these were used predominantly during walking segments, if at all, and failed to be contextually relevant while also distracting the participants. When we incorporated figural scale material in the MR tour we tied it directly to specific POIs in the visual field. This made all the information delivered at this scale contextually relevant, and freed up the participant's attention during walking segments, opening up a further design space to incorporate audio as discussed above. Furthermore, the unique affordances of digital media at the figural scale, the use of the multi-touch tablet screen, provided the opportunity to introduce multimedia content in the form of additional images, video, and text to more actively engage participants and give them a much wider selection of information than is possible to deliver in the analog tour.

An additional insight into how to use spatial scale effectively in the MR tour, came not from the tour itself, but from the interview study, and regards the limitations of information presented at the panoramic scale. Subject #3 intuitively believed that line-of-sight was required in order for a user of the Walking Dead TV Companion to comprehend the connections between adjoining panoramic spaces. This observation informed the design of the MR tour in two ways. First, in contrast to the dominant techniques in MR information browsers, like Yelp, we limited placemarks to the visible panoramic space. As noted in the accompanying user study, the one instance in which we failed to do this correctly was noticed by a tour participant and resulted in confusion, further supporting the veracity of this approach. A second instance of this approach came in the form of limiting the number of additional panoramas accessible from the current panorama to those that were immediately adjoining. While this constrained users' abilities to access information by jumping randomly from one panorama to the next, it also helps them construct a more consistent cognitive map of the relationships between places on campus, as was suggested by subject #3. This is also an example of scale-matching information to the scale of its presentation noted above. Panoramas or placemarks outside the line-of-sight are no longer panoramic scale representations, but environmental scale ones, because locomotion is required to view them, making sure not to present such environmental representations until they are part of the panoramic space keeps the information matched to the scale of its presentation.

Many additional elements of the MR tour incorporate principles of scale thinking as well. The automatic loading of panoramas when the user's GPS coordinates are within a given range is a type of scale-transition, helping them smoothly move from environmental space to panoramic space. The repetition of placemark images in the info-pane and the surrounding panorama provided users with coordinated representations that both focus their exploration of the information in the info pane, and provide a simple visual cue that they could use to re-orient themselves when they returned to looking at the panoramic space. The use of the pointing arrow to allow users to navigate the environmental space without the need to coordinate representations is a technique that came from the analysis of the BeeHive study and also one that is based in an understanding of scale-thinking. Finally, the construction of the database itself, and the hierarchy of web-tools used to manipulate and maintain it, were also heavily influenced by an understanding of spatial scale as described in Chapter 4.

Spatial scale was also shown to be a factor in participants' experience of the MR tour, although not to a significant extent due to the noted problems with experimental design. In addition to the participant mentioned above, who found the violation of the line-of-sight rule to be confusing, a number of participants demonstrated behaviors that were indicative of attempting to coordinate representations between spatial scales, as described in the BeeHive study. Other observations about behaviors at the panoramic scale were also noted, and pointed toward potential future work. For example, the fact that participants did not seem to think that being in the exact location from which the panorama was shot, demonstrated some robustness to the human cognitive system at that scale and I suggested that future research to push the limits of this ability would be very useful to MR design in general. Additional observations about the role of social factors in the tour experience surrounding group dynamics and device sharing were also observed and these suggested additional areas of potential research.

6.2 In Conclusion

> Hypothesis4. A multiscale framework for MR walking tours has rhetorical, descriptive, inferential, and application power as described by Halverson [ref].
>
> Questions4. Does the MRSF meet Halverson's criteria for a cognitive theory of HCI?

The final claim and conclusion of this dissertation, is that the MRSF meets the criteria of a cognitive theory for Human-Centered Computing (HCC)[1] laid out by Halverson (Halverson, 2002). A number of cognitive theories have been explored and adapted for use in HCC research. Activity Theory (AT) (Nardi, 1996), Distributed Cognition (DCOG) (Hutchins, 1996), and Situated Action (Suchman, 1987), are perhaps the most widely cited. Although the various merits and drawbacks to using or choosing one of these theories over another have been debated by numerous researchers with only slightly less numerous conclusions, the comparison of AT and DCog undertaken by

[1] I use the term HCC as a catch-all for the related fields of Human-Computer Interaction (HCI), Computer Supported Cooperative Work (CSCW), Digital Humanities, and other closely tied sub-disciplines.

Halverson (Halverson, 2002) is the most appropriate for the research I have described here.

In addition to discussing the merits of those other cognitive theories, Halverson outlines four specific attributes, what she refers to as "powers," for identifying a successful cognitive theory in HCC. These are: *rhetorical power, descriptive power, inferential power,* and *application power.* I will briefly summarize each in turn, and discuss how the individual contributions of this dissertation provide *converging evidence* supporting my claim that the MRSF demonstrates each of these powers. It should be noted at this point that Halverson does not suggest or expect any theory to possess all four powers, and certainly not in equal measure. Nevertheless, I will attempt to demonstrate the MRSF comes remarkably close, and perhaps even closer than many of the more common cognitive theories at work in HCC.

- Descriptive Power – The ability to describe a setting and critique a technological implementation within that setting.
- Rhetorical Power – The ability to name constructs in the world, and convince others that our view is correct.
- Inferential Power – The ability to form hypotheses and predict the consequences of our designs.
- Application Power – The ability to inform and guide system design. Descriptive Power

6.2.1 Descriptive Power

> First, we require descriptive power. Theory in CSCW should provide a conceptual framework that helps us make sense of and describe the world. This includes describing a work setting as well as critiquing an implementation of technology in that setting.
>
> (Halverson, p. 245)

As Halverson states, the value of descriptive power is that it can help us 'make sense of' the world. The two key elements of this power are the 'ability to describe a setting' and the 'ability to critique an implementation of technology in that setting.' The MRSF I describe in this dissertation is capable of doing both of these things. As evidence in support of the scale framework's descriptive power, I have given a number of detailed descriptions of both contexts for MR interventions and of those interventions themselves, two of the important points needed to demonstrate descriptive power. In Chapter 3 I describe the BeeHive study in terms of the MRSF and demonstrate how the framework both describes the basic navigation activities that the authors' MR implementation attempts to augment and the behaviors of participants in observed in that study. I also use the framework to critique this implementation, and provide alternative explanations for the phenomena those researchers observed, as well as alternative strategies based on the principle of spatial scale. In that same Chapter, I describe the design and evaluation of a single MR experience, [inbox] in terms of spatial scale and critique its effectiveness at communicating meaning to participants of that experience. Additionally, the descriptions of the role of scale in the design process, and the results of that process, derived from interview subjects also support the claim of descriptive power for the MRSF. The final support for the descriptive power of the MRSF comes from the scale analysis of the analog campus tour experience and the descriptions of the user experiences during the MR version of that tour also contribute. I believe that these studies aptly demonstrate that the MRSF can be used to describe a setting and critique the application of MR technology in that setting, the two requirements Halverson suggests for demonstrating descriptive power.

6.2.2 Rhetorical Power

> Second, we need rhetorical power. Theory should help us talk about the world by naming important aspects of the conceptual structure and how it maps to the real world. This is both how we describe things to ourselves and how we communicate about it to others. Further, it should help us persuade others that our view is correct.
>
> (Halverson, p. 245)

As Halverson understands it, rhetorical power encompasses a number of important functions for any theoretical framework. The first of these is the ability to 'name important aspects of the conceptual structure.' Although the meaning of this is somewhat ambiguous, she elaborates further on this idea in her discussion of Activity Theory (AT), a framework she believes names things well. Of primary importance is naming the "unit of analysis," the "activity" in AT. As it is with AT, and perhaps any rhetorically powerful framework, the unit of analysis is built into the name, in this case scale is that unit of analysis. However when using scale as a sensitizing concept for thinking and talking about the work of others spatial scale offers similar insights. For theories such as Milgram & Kishino's virtuality continuum and the ARGs studied by McGonigal and others, spatial scale helps them define their object of inquiry and unit of analysis. For the theory of MR Boundaries offered by Benford et al., I showed that their categories of topology, orientation, movement, and containment, corresponded directly to the scales of the MRSF, essentially giving them new names within the MRSF. I then used a number of rhetorical techniques to derive a new definition of MR that encompasses all of these that is rooted in the MRSF. This is the core of the evidence supporting the rhetorical power of the MRSF. However, it is not the only evidence.

In Chapter 2 I examine a number of well-known canonical examples of MR experiences and show how each can be classified (named) according to its scale and discuss what this implies about its structure and function. This demonstrates not only that the MRSF has the ability to "name important aspects of the conceptual structure," but that doing so in the context of real world examples also shows how these names 'map to the real world.' I have also named a number of important constructs in the multiscale design throughout this dissertation, such as *scale transitions,* and the *coordination of representations,* and *scale matching*. The inclusion of techniques such as the use of *embodied triggers*, *panoramic slides*, and *environmental approximation* are also named constructs derived from the MRSF. Additionally, at a higher level, this entire dissertation serves to communicate the important aspects of the MRSF, and works to persuade you (the reader) that this view is correct and is itself a demonstration of rhetorical power.

6.2.3 Inferential Power

> The third attribute is inferential power. Without engaging in arguments about whether theories are true, or only falsifiable (Popper, 1992), we do want a theory to help us make inferences. In some cases those inferences may be about phenomena that we have not yet understood sufficiently to know where or how to look. We may hope that inferences will lead to insights for design. Or we may want to predict the consequences of introducing change into a particular setting.
>
> (Halverson, p. 245)

Inferential power comes in many forms and, coincidentally, many levels. In MR, one might make inferences about what representations to use, what strategies should be employed and why, or who an experience will engage most effectively. Throughout this work I have made a number of hypotheses based on an understanding of spatial scale. Some of the larger and more important ones I have addressed directly in this dissertation, and summarized above, but other inferences can be found on a variety of subjects. The idea of “Language of MR” based on spatial scale, and the association of scale transitions with film editing discussed in the previous Chapter is perhaps the largest and most far-reaching of these inferences. However, I have also made smaller and more focused inferences. For example, in Chapter 2 I suggested, as a testable hypothesis, one possible “first-person strategy” that players of the game Levelhead might employ: Adopting an egocentric view of the multiscale space of the cube-world, which was reasoned from spatial scale. Again, the analyses of both the BeeHive and [inbox] studies in Chapter 3 come into play, particularly because I use spatial scale to draw inferences about the mental states of users of these systems that would not have been possible from observations of their behavior alone. Having a framework, such as the MRSF, provides the structure for interpreting and observations and data that helps us reason and draw conclusions, as Halverson suggests. More tangibly, some of the other inferences I have made in regard to those studies surround ideas about how spatial scale might have been used more effectively if the MRSF was available to inform design decisions. These would be easily testable in well-designed comparative user study.

I also made a number of inferences in regard to the campus tour. Some of these, such as the lack of coordination between figural and panoramic content in the analog tour, were provided "insight" for the design of the MR version as Halverson suggests. Other inferences made in this context though were helpful in understanding how to introduce change, through MR technology, into the tour itself. These are sometimes more subtle, because understanding the consequences of introducing change may often involve providing the right reasoning for *not* doing something, and therefore are somewhat harder to detect. A good example of this is the role of the tour guide in the analog tour. This guide plays an incredibly important role, and the use of a self-facilitated MR would effectively eliminate this element. Understanding spatial scale allowed us to first identify the importance of this guide, his role at both the panoramic and environmental scales, and to consciously attempt to provide a mechanism, playing audio files in-between panoramas, that could potentially preserve his role in the tour. A deeper study looking at the scale-matching of information delivered while walking in the analog versus MR tours could potentially make this feature much more robust, an aspect that we might not have looked at without a sensitivity to scale.

6.2.4 Application Power

> An important fourth attribute has to do with application: how we can apply the theory to the real world for essentially pragmatic reasons. Mostly this translates to our need to inform and guide system design. We need to describe and understand the world at the right level of analysis in order to bridge the gap from description to design.
>
> (Halverson, p. 245)

While it could be said that using a framework to describe a system, a situation, or ways of thinking and interacting are all "applications" of that framework, those uses are accounted for in the descriptive and rhetorical power of that framework, and is not the sense that Halverson uses "application" here. Application power refers very specifically to the ability of a framework to inform design, to "bridge the gap from description to design." The demonstration of the application power of the MRSF can be wholly accounted for in the design of the MR campus tour. While it is arguably that because scale is so deeply embedded in our thinking about space it will inevitably inform system design at some level, this is different than using it consciously. In that sense, the most ideal support for the application power of spatial scale and the concepts I have outlined in this dissertation would come from many designers using the theory to create their designs and all agreeing that it was instrumental to their success. I sincerely hope that that happens one day, but it hasn't happened yet. For the time being, the major evidence in support of the application power of the MRSF, comes from the fact that an entire MR campus tour application and supporting infrastructure was created within the context of the MRSF, and that this system has been successfully deployed in the field. The MR campus tour application described was created from the top down using the MRSF and it is the first conscious embodiment of multiscale design for MR systems. It was successfully used in the evaluation study, but more significantly, it persists beyond this dissertation as part of suite of applications being developed under the banner of "GT Journey[2]," and intended as a technological platform to allow GT students to create and consume their own virtual content throughout their time at Georgia Tech and beyond.

6.2.5 Conclusions

There are a number of conclusions that can be drawn from the work contained in this dissertation. First and foremost, I have shown conclusively that spatial scale and scale-thinking fundamentally underlie the research, design, and use of MR systems, a fact that has never been hypothesized or demonstrated before. Arming ourselves with this knowledge will add to the depth of our understanding and thinking about these systems and their use, as well as add to our overall understanding of the scale principles of spatial cognition in general. As a means of embodying this knowledge and making it accessible and actionable for future researcher and designers alike, I have presented the Mixed

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[2] http://ipat.gatech.edu/gt-journey

Reality Scale Framework, which I have shown does indeed qualify as a cognitive theory for Human-Centered Computing using the criteria outlined by Halverson. I have shown that it is possible to deconstruct MR experiences into elements that operate at individual spatial scales, and that analyzing the way different MR systems mediate our spatial experience between these scales is a productive means of locating opportunities for design intervention. These interventions might simply be improvements to existing MR systems that comes from the insights gained through scale-analysis, or they might be the development of entirely new systems based on knowledge gained through scale-analysis of particular domain, as was shown in the campus tour example.

As a means of helping MR researchers and developers understand the relationships between spatial scales embodied in MR experiences I have offered the concepts of coordination of representations, scale transitions, and scale-matching to seed further thinking and analysis. I have shown that these ideas are often intuitively present in the design and use of MR systems and explained that issues in the use of MR systems can often be explained as in terms of these concepts. For MR designers, I have offered some more specific guidelines to inform their design and named these to make them accessible as concepts. These are environmental approximation, panoramic sliding, and embodied triggers. As a final contribution, I have, along with a development team, created the GTour application and the tools needed for its continued use and made these available to the Georgia Tech community, in the hopes that they may serve as touch point for future research, and become a part of a more permanent digital presence on the Georgia Tech campus.

All of this work, I believe, firmly supports the statement that:

A multiscale framework for Mixed Reality walking tours can identify new constructs for design and analysis, inform design decisions, explain empirical results, and guide the development of a MR walking tour and the tools for its creation and maintenance.

APPENDIX A

THE DISAPPEARING CATEGORY OF NON-MANIPULABLE OBJECT SPACE

Despite being rigorous and well-reasoned Freundschuh and Egenhofer's taxonomy has some ambiguity to it that must be discussed; most notably, the use of *size* as a determining factor. Size is a qualitatively different construct than either locomotion or manipulation, as it is not a binary, on/off, function. One can walk or not walk, manipulate or not, but size is a continuum. This problem of size reveals itself in the underspecified and relativistic use of the term that appears not only in their taxonomy of space, but in nearly all the models of spatial scale from which it is constructed. The importance of size is not without precedent however, Ittelson [ref] made a size distinction based on objects and spaces that are either smaller than or larger than the human body. Yet, his distinction is not based solely on size, it is size relative to the human body, and so is rooted in the concept embodiment (internal representation in the mind based on the physical experience of the body). While the recurring use of size as a factor in taxonomies of spatial scale suggests that the notion is functional and useful, it does not mean it is always the best choice. The lack of well-defined *boundaries* makes its application haphazard at best. Consequently, nearly all Freundschuh & Egenhofer's categories include ambiguous, subjective and even contradictory notions of size, suggesting that there is more at work in the human perception of spatial scales than is accounted for in their taxonomy, and more work to be done in elucidating the factors that demarcate spatial scales in practice.

Nevertheless, we do want to try and create, or at least define, discrete categories so that we may reliably and systematically classify MR experiences as one type or another, and to create reliable and reusable constructs from which to base measurements and designs. For this reason, I would like to introduce the notion of *boundaries* as a heuristic in place of the idea of size. Boundaries are, of course, intimately connected to size. Saying that something has a size implies that it does, indeed, have boundaries, it is not infinite. Even looking into the far off and infinite reaches of outer-space is bounded by the limits of the human eye. More applicably, a panoramic view from a mountaintop would also be bounded by the limits of human vision in the same way that the panorama you see inside your shower would be bounded by the limits of your vision, attributable to your walls. While these two spaces vary greatly in size they are both bounded by *unobstructed-line-of-sight* and therefore might rightly be considered the same type of space despite enormous differences in size.

Let us consider another example using panoramic space. Imagine a typical office building with many rooms and floors, each individual room is experienced from the center as a single panoramic space bounded in size by the internal walls of the building. To experience the whole building an observer would have to locomote to every room, making the building an environmental space. Now imagine the same building without any floors or walls, simply an empty shell. This same building would now be perceived from an observer in the lobby as a single panoramic space. The actual size of the space has not changed, only the boundaries. Thus one can have panoramic and environmental spaces that are of the same size, but differ only in their requirement for locomotion. This notion is in keeping with the distinctions found by Freundschuh & Egenhofer, while it also suggests that size is only a determining factor of spatial type in so far as it is the result of boundaries. The use of boundaries is also somewhat consistent with the embodied cognition view, in that such boundaries limit the physical movement (or vision) of an observer, as well as define the size of the space. I know that I cannot move through a wall and so this is a natural, physical limit to my movement.

One category found in Freundshuh and Egenhofer's taxonomy but absent in Montello's is *Non-manipulable object space*, defined as:

> … non-manipulable, small spaces requiring locomotion to experience them. These include objects larger than the human body and typically smaller than house-size spaces (e.g., cars, elephants, trees).
>
> [ref p. 11]

Non-manipulable object space presents an interesting problem. On the one hand, it is non-manipulable like a panoramic space, but requires locomotion, like an environment. By the above definition, such spaces seem not to be spaces at all, only objects, and the examples they give of cars, elephants, and trees, as well as the name itself underscore this point. Second, these "spaces" seem also to not be distinct. While they require locomotion to experience them, and are non-manipulable, they are too small to be considered environments, so size is their major distinction. This is arbitrary to the point of being problematic. The heuristic "house-sized" spaces, is not particularly useful. Whose house are we talking about? Mine or Bill Gates's?

If we examine how one of these non-manipulable object spaces might be experienced, treating the perception of space as our starting point rather than the space itself, we can imagine two possibilities. For one, it might be viewed closely, and potentially tangibly. For example, one could walk around a car (or an elephant) that they are thinking of purchasing and "kick the tires" so to speak, by touching the paint, the door handles, looking in the …um…trunk. In this way, the space becomes manipulable as a series of successive figural spaces. Secondly, taking a literal and figurative step back, one might walk around the car or elephant to get different views, vistas of the space. This space could be of the panoramic scale, in which individual vistas are integrated over time into a seamless collection of images, this is a more purely "symbolic" ordering. Yet, the act of walking can be said to define this space as an environmental space. In all cases the car/elephant remain the same object, but the experience of that object takes different forms. Observation of prospective buyers of cars (and presumably elephants) demonstrates that they often take all of these approaches, because they yield different information about the "look" and "feel" of the object. This suggests that designing for all these different modes of spatial experience is a valuable strategy.

The problem that examining an object in non-manipulable object space requires locomotion, the defining characteristic of environmental space is an compelling one. This is indeed a problem, since I contend that the MRSF defines scales based on the physical experience of space. Montello addresses this issue rather simply, and perhaps unconsciously, using the term "appreciable" to describe the kind of locomotion possible in vista spaces. One might also make the claim that the length of time it takes to walk around a car is much less then the length of time it takes to walk around a college campus. Or, one could take the position, as Freundshuh & Egenhofer, do that the size of the space in question is what matters. These are extremely fuzzy boundaries however, and as such they break apart very quickly. Essentially, the choice of how to treat these kinds of boundary cases boils down to where one wants to put the ambiguity. Freundshuh & Egenhofer chose size as the ambiguous dimension. Exactly how large does a space need to be before it ceases to be a non-manipulable object space and becomes an environment? Montello, on the other hand introduces the ambiguity in his use of the modifier "appreciable" in regard to locomotion. How much locomotion is appreciable enough for a vista to become an environment? Furthermore, one might chose alternatives such as time (to walk around) or distance as demarcation points. Even the notion that whether one is focusing on the object itself, or the surroundings, can come into play; a distinction Benford describes as "focus" vs. "nimbus" [ref]. These are sticky philosophical questions that arise from the fact that we are trying to derive discrete categories from the otherwise continuous experience of space; digitizing the analog to use a metaphor from computer science. Like all philosophical questions they invite thought experiments, and so I offer this one.

Continuing with the example of examining a car from multiple perspectives, imagine that you were no longer looking at the car, but facing the opposite direction, looking off into the environment. If you were to walk the same path in this new orientation you would essentially be viewing a panoramic space, constructing its mental representation by integrating multiple vistas over time. The result of doing this through walking a circle around the car, versus standing at the center of the car and rotating around is essentially negligible, suggesting that the locomotion is not "appreciably" different than simple rotation. If the object were larger, a building for example, the effect is the same. Looking outward into the environment is a panoramic view similar to what one would assemble from looking outward from the center point of the building. Looking inward, toward the center of the building is therefore also panoramic, as the distance is the same, but only the orientation has changed. This is a worthwhile heuristic for determining the scale of the spatial experience, but it also helps us draw an inference about panoramic spaces in general. Namely, that they can be *outside-in* as well as *inside-out*. Furthermore, while we have tools in the form of camera lenses and software that assemble inside-out panoramic spaces [refs], we do not have them for outside-in spaces, and so the creation of such a software tool is one suggestion for future work that comes from a deep interrogation of the MRSF.

This is a not entirely satisfactory conclusion however. In order to argue, as I have been attempting to do, that the MRSF defines spaces based on their embodied characteristics it would seem that locomotion in any form should define an environmental scale *experience* regardless of the size of the space, the amount (appreciable or not) of locomotion, or any other factor. This point seems particularly salient when one considers that operations on an object might be triggered by interactions at other scales. For example, walking around a building might trigger actions on an object sitting on a desk, a map of people in the building for example. The object itself might be figural scale, but the interaction with it occurs at the environmental scale. There is no convenient solution to this problem. For one, we might consider that the virtual information is being mapped into the figural space, and so consider it a figural scale experience. On the other hand we might care more about the sensing and positioning technologies at the environmental scale that are being used to generate the representation.

APPENDIX B

THE CAMPUS TOUR AS WALKABOUT

The Georgia Tech campus tour, in analog (and MR), is a multiscale experience. The tour involves locomotion through large areas that cannot be apprehended entirely from one location, and that occur over lengths of time on the order of hours rather than minutes. These facts mark the environmental scale elements of these experiences, and this is the primary scale at which these experiences are intended to make meaning. The point of taking one of these tours is to get a “sense” of the institute as a whole, to build a cognitive map of the space and the culture. To accomplish this goal the tour must communicate to a participant the information they need to understand the environment, the Georgia Institute of Technology in this case. However, the tour I examine here and the general class of cultural heritage tours that this analysis applies to, involve elements at the panoramic, vista, figural, and global scales as well, and a properly designed tour must integrate information at all of these scales to achieve its objective.

In this chapter I examine the Georgia Tech campus tour as a case-study in multiscale design. I begin by analyzing the analog walking tour according to spatial scale and determine that the tour effectively communicates with its participants through the embodiment of *mental and cultural models* at various scales. Using scale as a sensitizing concept during participant-observation of the analog tour I identify a number of opportunities for a MR version of the tour to transform the tour experience while maintaining its essential structure. These include the observation that figural scale materials fail to coordinate with representations at the panoramic scale, and the fact that user behaviors indicate the expectation for the scale of information being delivered is relevant to current scale of their experience, a concept I summarize as *scale-matching.* The ability of the MR version of this tour to effectively use *scale transitions* like those discussed in the previous chapter is later shown to be distinct benefit of using MR technologies in this context. Additional aspects of the MR implementation are discussed, including the use of global framing as a strategy for overall tour design and it's "trickle-down" effect in organizing tour data, the construction of a database that facilitates the implementation of scale transitions and scale matching, and reliance on scale-thinking to guide the creation of tools to maintain that database.

The final section of this chapter discusses an evaluation of the MR tour experience in the wild through the use of participant observation and focus groups with 30 middle school students. Evidence of scale-thinking and reasoning in the context of the tour experience are discussed. These include the ability of participants to recognize data that was "out-of-scale," evidence of the coordination of representations being used outside the context of navigation, and the ability of participants to effectively use the tour despite offsets in the viewing location of panoramic spaces that resulted in misalignment of virtual representations. Additional issues surrounding the influence of social factors in the tour experience are also identified and discussed.

B.1 Mental and Cultural Models at Multiple Scales

To understand how the Georgia Tech tour accomplishes the goal of communicating meaningful information at multiple scales, I will examine the structure and function of the typical campus walking tour experience from the critical perspectives offered by the MRSF and the work of the cognitive anthropologist Bradd Shore (Shore, 1996), whose conceptualization of the relationship between cultural experience and human cognition is formulated in terms mental and cultural models. I stated above that the goal of a campus tour is to communicate what the experience of being a GT student is like, and to convince prospective students that they belong there (or not).

One way to conceptualize this goal of the tour would be to say that the designers want participants to come away with a *mental model* of Georgia Tech as a unique culture or place, as well as some idea of their personal relationship to this culture, what we might refer to as their *identity* in relation to it. This mental model must necessarily consist of many elements, such as the academic and social life of the institution, its traditions, and its relationship to the rest of the world. These elements of Georgia Tech's culture must be communicated during the on-campus visit, and the campus tour is the medium for this communication. Shore conceives of culture as a collection of *cultural models* and campus tourism is rife with these models at every scale. He also identifies the role of ritual as the primary means by which models are communicated from cultures to individuals.

B.1.1 The Walkabout as a Model for MR Walking Tours

Campus tours are extremely common among college-bound high school students who use them to gauge what a particular university experience might be like, and to decide which university might be the best "fit" for their educational (and social) future. Participation in these tours has become a kind of ritual practice, at least in the life of the American teenager. Like all rituals, they are repeated over and over, year after year, at universities all over the country; they have changed very little in their long, yet surprisingly undocumented history; and most importantly, they involve the twin processes of *identity formation* and *cultural reproduction* that are at the heart of ritual practices.

The structure of the campus tour, in which an individual walks around campus, seeing the buildings and students, hearing stories and learning facts, and generally experiencing the campus through their physical senses and cognitive sensibilities, points toward a model of spatial experience, the ritual form of the *walkabout,* which I believe can help us understand the cognitive processes involved in the construction of meaning during the campus tour. The walkabout is a trajectory through space and place that integrates somatosensory experience with symbolic representation to produce individual identity in relation to culture. My contention is that not only do these tour experiences resemble the form and structure of the walkabout, they also draw upon many of the same cognitive processes and achieve the same outcomes.

While many researchers have theorized about the social and personal implications of ritual, Shore offers an analysis of the aboriginal walkabout that is particularly appropriate as a model for campus walking tours. The traditional walkabout is a ritual journey in which individuals walk out into the wilderness, following the paths, or "songlines," (Chatwin, 1988) of their ancestors, or else ceremonially mimic and reproduce these songlines, with the goal of creating a personal connection to the places and events mentioned therein. Walkabouts are participatory, spatialized narrative experiences that connect individuals to their culture and, according to Shore, instill cultural models through both symbolic and somatic experience.

Shore conceptualizes cultural experience in general, and the walkabout in particular, as complementary processes of the *internalization* and *externalization* of models. Internalization refers to the process of creating a *mental model* that has features common to the external cultural model, yet, is also transformed in some personally significant way. During a walkabout, a mental model is formed from direct physical experience of places and objects and characterizes the individual in relation to the culture-at-large, this is the formation of identity with respect to a culture. This is also the goal the campus tour, creating a meaningful connection between the participant and the cultural models being presented. Cultural models are tied to artifacts around the campus, such as buildings, sculptures, or landmarks, as well as stories and events that are shared by the culture-at-large, and so all of these should be embodied and represented within an effective tour.

B.1.2 Cognitive Maps as Models

A number of authors, including Shore, view information about place, in the form of cognitive maps, as resulting from a sense-making process that uses myth and ritual as the context for meaning. Because the campus tour necessarily involves the construction of a cognitive map, understanding the tour as a ritual form, and analyzing the various myths and rituals embodied in the tour can help us better understand how these tours create a sense of place in their participants. Cognitive maps are an example of personal mental models.

> I have also created several mental maps of my neighborhood and my city, each of which bears only a very schematic relation to its actual layout. Each map employs landmarks of special interest to me, such as the houses of neighbors I know or the highway exits relevant for my habitual journeys…These various maps are all mental models that have been personally constructed or "schematized" by myself and my family as a normal part of our negotiation of our physical and social world.
>
> (Shore 1996, p. 46)

Shore acknowledges that these maps have both a spatial and cultural (place) component. He suggests that *analogical schematization* is the mechanism by which these maps are internalized in the mind, and in language that squares with the traditional cognitive science approach to this problem, sketches out the operations that compose this schematization process:

> Details are reduced in complexity and at times eliminated altogether, while s*alient features of an environment are selected and sometimes exaggerated or otherwise transformed* by a process of formalization and simplification–a process I call "schematization."
>
> (Shore 1996, p. 47 italics added)

I have italicized what I believe is the most relevant part of this quotation for the understanding of walking tours. The idea that salient features are exaggerated and transformed in the process of schematizing a cognitive map, suggests that a tour experience which highlights specific aspects of the environment, both spatially and culturally, privileges certain features over others. These highlighted features enjoy increased salience in the formation of individual cognitive maps, and so should be the focus of a design strategy.

B.1.3 Internalization of Models

The internalization of models through analogical schematization is also part of the process by which the second sub-type of mental models, *conventional mental models,* are formed. In contrast to idiosyncratic *personal mental models*, conventional mental models are shared by all members of a community, and are therefore cultural models as well. The schematization of conventional mental models also integrates personal experience, but is more closely tied to cultural artifacts, like narratives, places, and customs. This makes them function more as internal representations of culture than as constituent elements of identity. The difference could be summarized this way, personal mental models are what an individual believes while conventional mental models are commonly held beliefs. This difference is an important one, because it allows Shore to make a number of important connections. He describes the internalization of cultural models into conventional mental models as follows:

> Cultural models are constructed as mental representations in the same way as any mental models with the important exception that the internalization of cultural models is based on more socially constrained experiences than is the case for idiosyncratic models. Cultural practices that *constrain attention and guide what is perceived as salient* are not left open to much personal choice but are closely guided by social norms…Such "shared" cultural models will not produce total cognitive homogeneity among individuals within a community but rather a tendency for personal models to overlap far more than they would if left to purely individual experience. This is the conventionalization of memory through ritual…
>
> (Shore 1996, italics added)

Again I have added emphasis here to show what I think is the important takeaway for the design of walking tours. The notions that cultural practices "constrain attention" and "guide salience" are important concepts in tour design. Tour guides, both physical and virtual, constrain attention by isolating important people, places, objects, and features of the environment. They must direct visitors toward the salient features of these artifacts. Furthermore, in doing so, the guides are identifying what features are considered to be salient by the community. These shared features and the models they comprise fall under the category of *externalizations* of culture, and creating them is the goal of tour design.

B.1.4 Externalization

In the design of walking tours curators create a number of derivative works such as maps, pamphlets, plaques, or, more recently, audio and other multimedia artifacts with which MR techniques might be grouped as well. All of these artifacts fall into Shore's category of *externalizations* of culture. Participants encounter these externalizations, internalize them into conventional mental models and leave with a personal mental model of the culture. According to this reasoning then, the goal of technological interventions in the context of walking tours in general, and in the MR campus tour specifically, should be to aid in sustaining this dialectical process of externalization and internalization; to help designers externalize cultural models, and to help participants internalize those models into mental models of both types.

Externalization specifically refers to the process by which mental models are embodied in artifacts and practices, and Shore calls the results of this process, the derivative works noted above for example, *instituted models*. As externalized forms of cultural models, instituted models encompass a broad range of cultural artifacts from patterned behaviors to physical objects. Shore describes these models and explains their "double-life" in the social world and the role they play in the schematization process:

> Instituted models are social institutions- conventional, patterned public forms such as greetings, calendars, cockfights, discourse genres, houses, public spaces, chants, conventional body postures, and even deliberately orchestrated aromas…They are models in two different senses. First, instituted models are human inventions, the product of continual social production of publicly available forms. Instituted models are the externalization in the social world of particular *models of* experience. Second, to the extent to which these instituted models govern concept formation of newly socialized individuals, they are also *models from* which individuals construct more or less conventional mental models.
>
> (Shore 1996, p. 51 italics in original)

Instituted models include physical artifacts, such as ceremonial costumes or objects; conceptual artifacts like stories and events; and even natural artifacts, like mountains and streams in so far as their interpretations are common throughout a culture. All of these artifacts are meaningfully shared by everyone in the culture, and undergo continual transformation from instituted models to mental models and back again. The double life these models lead refers to their role as externalized models of culture, as well as the use of these models in the formation of conventional mental models through internalization. Shore denotes these differences with his use of the "models of" and "models from" phrasing. Applying this perspective to the campus walking tour, we can see that they are embedded throughout with instituted models, and their goal is to communicate these models so that visitors can form their own conventional mental models. Finally, each participant must compare the conventional mental models they come away with to their own personal mental models and then decide if these models suit their identity.

B.1.5 Embodied Experience meets Symbolic Representation

The construction of identity outlined above is identical to one that occurs in the walkabout schema described by Shore. An individual, called an initiate, follows the songlines of his ancestors (physically and/or symbolically), and in doing so internalizes the conventional models embedded in the narratives and myths that constitute the songlines. This internalization is accomplished through a combination of somatic and symbolic experience. However, this is only part of the process, the initiate is also expected to acquire their own personal models of these songlines and this personal interpretation is understood to be indicative of their own identity in the tribe. Shore further explains this aspect of the walkabout in relation to two distinct forms of human memory, which is valuable because it helps us relate the physical experience of space to the more symbolic representations of place and culture. The first, "procedural" memory, is associated with sensory-motor processes and he summarizes its function as follows:

> Its function is to store and retrieve general schemas of repeated action patterns. Many everyday actions such as walking, throwing a ball, threading a needle, or peeling a potato are constituted in memory as motor schemas and algorithms, coordinating sight, touch, and other sensory modalities.
>
> (Shore, 1996, p. 258)

It is not a coincidence that the actions Shore names as being encoded in procedural memory are also the embodied interactions that define the scales of the MRSF. I have argued throughout this work that these actions activate particular and distinct cognitive structure. However, this is only one level at which the walkabout makes meaning for an initiate. There are higher order cognitive functions involved as well, and Shore relates these to the symbolic and language manipulation functions of the brain, particularly semantic memory.

> Semantic memory involves the capacity to invent signs, the intentional manipulation of symbols, and the attribution of shared meaning to arbitrary or conventional signifiers such as combinations of sound or writing or gesture.
>
> (Shore, 1996, p. 259)

The power of the walkabout lies in its ability to combine these two distinct modes of experience, through *participation* in the ritual. In Chapter 2 I noted that Virtual Reality researchers and ARG researchers have different ideas about immersion. In VR, immersion is taken to describe purely sensory-motor elements and is indicative of an overall emphasis on physical experience, while ARG researchers, like McGonigal, describe immersion in terms of higher-order cognitive processes, such as belief. It appears as if the walkabout combines both of these notions, just as the MRSF does. Thus, there is a direct connection here between what Shore calls the "multivocal resonance" of mental and cultural models in the walkabout, and the multiscale design of the campus tour which suggests that such models are perhaps the right construct to center our analysis of the tour experience.

The first thing to notice is the color. The page is branded with the official Georgia Tech Black and Gold color scheme and so serves to communicate the importance and relevance of these colors to visitors. These colors not only brand the page itself, but also the students in the banner image. Those students, who adorn body paint and costume elements in those same colors, call to mind the rich and numerous accounts of aboriginal cultures, chronicled by Shore and others, who paint their bodies as part of their ritual practices. The action in the image itself, which is presumably taking place at some form of sporting or other event ensconced in "school spirit," is no doubt intended to communicate the importance and relevance of these events, to the community as a whole. This is also an instituted cultural model, and one unmistakably encoded in ritual practice.

The first line of text also resonates: "The best way for you to see if Georgia Tech is the right place for you is to visit and experience the Tech campus for yourself!" Persuasive language and enthusiasm aside, there are three important connections here. This sentence seems clearly to be about the construction of personal and conventional mental models. For one, it calls upon the notion of "place" which we know is connected to both space and culture, and integral to the formation of cognitive maps. Second, the overall content seems to suggest that the correct way to form a personal mental model of Georgia Tech, one idiosyncratic and commensurate with identity, is to be physically present in the environment, so as to "experience" the instituted models through participation. The suggestion for how to do this is through a walking tour. Presumably, the designers of this site had no knowledge of anything like personal, conventional, or instituted models, and are simply using the most natural language they could to communicate the importance of a campus visit. The very obviousness of this short block of text, and the assumptions it makes about "the best way" to understand the community and determine its "fit" for you, reveals that the processes I have outlined above are appropriately descriptive of the basic intuitions the creators of this site have about identity formation in relation to campus visits.

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